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(54) Title: FORWARD ERROR CORRECTION ON MULTIPLEXED CDMA CHANNELS ENABLING HIGH PERFORMANCE CODING

(57) Abstract

A protocol for optimizing the use of coded transmissions such as over wireless links. In this technique, interframes are first split into segments selected to be an optimum size according to transmission characteristics of the radio channel. Segments are assigned a position identifier and redundancy check sum. Segments are then assembled into blocks and a forward error correction algorithm is applied to the block to generate redundancy bits. The FEC block is then split up among available communication channels and forwarded to the receiver. The inverse process is applied at the receiver. Using this scheme, only segments containing erroneous data need to be resent. A large block size required for high performance forward error correction may therefore be used while at the same time minimizing latencies associated with the need to resend entire blocks when errors cannot be recovered.

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FORWARD ERROR CORRECTION ON MULTIPLEXED CDMA CHANNELS ENABLING HIGH PERFORMANCE CODING

BACKGROUND OF THE INVENTION

The widespread availability of personal computers at low cost has led to a situation where the public demands access to the Internet and other computer networks at the lowest possible cost. This demand is being transferred to the need to also provide network access for portable devices such as laptop computers, personal digital assistants, and the like. Users of such portable devices even now expect to be able to access such computer networks with the same convenience that they have grown accustomed to when using wire line connections.

Unfortunately, there is still no widely available satisfactory solution for providing low cost wireless access to the Internet at high speed. At the present time, the users of wireless modems that operate with the existing cellular telephone network often experience a difficult time when trying to, for example, view Web pages. This is at least in part due to the fact that the architecture of cellular telephone networks was originally designed to support voice communication and not the packet-oriented data communication protocols in use for the Internet. In addition, the protocols used for connecting users of wide area networks do not lend themselves to efficient transmission over wireless interfaces.

Certain protocols have been proposed that provide multiple data links over a wireless communication system such as one that uses code division multiple access

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(CDMA). For example, one such system was described in our co-pending United States patent application entitled "A Protocol Conversion and Bandwidth Reduction Technique Providing Multiple nB+D ISDN Basic Rate Interface Links Over a Wireless Code Division Multiple Access Communication System," Serial No. 08/992,759 filed December 17, 1997 and assigned to Tantivy Communications, Inc., the assignee of the present application. With such techniques, high speed data service can be provided over digital cellular connections through a more efficient allocation of access to the wireless channels. In particular, a number of sub-channels are defined within a standard CDMA channel bandwidth, such as by assigning a different code to each sub-channel. The instantaneous bandwidth needs of a given connection are then met by dynamically allocating multiple sub-channels on an as-needed basis for each session. For example, sub-channels can be granted during times when the subscriber bandwidth requirements are relatively high, such as when downloading Web pages. The bandwidth is then released during times when the content is relatively light, such as when the user is reading a previously downloaded Web page.

However, to implement such a system requires careful planning of various modulation and coding schemes in order to accomplish the maximum possible bit rate while minimizing the effects of noise, multipath, and other sources of errors. For example, modulation codes and pseudorandom spreading codes must be carefully selected to minimize interference among channels occupying the same radio frequency carrier. In addition, it is necessary for framing bits to be inserted in data streams so that higher layered data

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protocols such as transmission control protocol/Internet protocol (TCP/IP) communication can take place.

SUMMARY OF THE INVENTION

Statement of the Problem

While the above-mentioned systems work well in relatively noise-free environments, they are not optimal in certain respects.

For example, although a cyclic redundancy check (CRC) error can indicate that a TCP/IP frame is received in error, use of a CRC is not optimum in that reception of an erroneous frame requires retransmission of the entire frame. Unfortunately, access techniques which require retransmission are particularly troublesome in shared access wireless environments such as CDMA where access must be specifically granted to accommodate the retransmission. For example, in CDMA systems, the errors can actually have a non-linear effect, reducing system capacity by an amount which is greater than the retransmission bandwidth. It is therefore desirable to minimize the need to retransmit data as much as possible.

Certain techniques known as forward error correction (FEC) are generally used with CDMA and other multiple access modulation schemes applied to voice transmission. Such techniques accept a group of bits, or "block," to be sent over a wireless channel and then, according to sophisticated mathematical algorithms, determine values for additional redundant bits. The number of redundant bits may be quite significant. For example, it is common to use so-called one-half rate, one-third rate, or even one-quarter rate codes whereby the number of bits in a block actually transmitted

increases by a factor of two, three, or four respectively.

The forward error correcting code can therefore be used to not only detect that a particular string of bits has been received in error, but also to implement error correction. This eliminates the need to retransmit an entire packet due to an error in one or more bits. Forward error correction has thus been widely used in implementations such as satellite broadcast where retransmission is impractical and/or expensive.

Unfortunately, implementation of forward error correction leads to lower overall throughput as measured by the number of packets transmitted per megahertz of available channel bandwidth. In addition, the need to obtain the best error performance typically dictates that a relatively large block size be used for the highest performance algorithms. Implementation of such error correction algorithms therefore incurs latencies in that the entire block must be available at the receiver before it can be decoded. In addition, if an error is detected which cannot be recovered through the forward error correction process, additional latencies are incurred while the block is retransmitted.

Brief Description of the Invention

The present invention is implemented using a protocol converter disposed between the physical communication layers, such as may be associated with implementing a wireless communication protocol, and a network layer, such as may be associated with implementing a network communications protocol.

Briefly, in the present invention, the protocol converter on the transmitter side first splits a network layer frame, such as a TCP/IP frame, into smaller

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portions referred to as segments. The segment size is variable in length according to an observed error rate. A minimum segment size, for example, is two bytes and a maximum segment size is 512 bytes in a preferred embodiment. All segments across a frame are equal in size.

Information is then added to each of the segments to permit their reassembly into the frame at the receiver. In particular, a segment position number is added to permit the segment to be placed into the proper position when reconstructing the network layer frame at the receiver.

At this point, the segments are arranged into groups referred to herein as blocks. A forward error correction (FEC) algorithm is then applied to the block as a whole. In a preferred embodiment, a block contains 1331 information bits. Therefore, using a one-third rate code, the FEC encoding process provides an output FEC block of 4096 bits.

The protocol also preferably makes use of multiple physical layer connections referred to herein as sub-channels to transmit the encoded FEC blocks at an overall desired transmission rate. The FEC block is then split among the allocated sub-channels such as on a bit-by-bit basis. The bits comprising the FEC block are then sent over the sub-channels. In this case, a link sequence identifier may typically also be added to identify the order in which the outgoing blocks are sent over the sub-channels.

On the receiver side, which in effect includes a protocol converter that performs the inverse function, bits received over the various sub-channels are first assembled into an FEC block. The FEC block, in the preferred embodiment as a block of 4096 bits, are then

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presented to the inverse FEC algorithm to strip off the redundant code bits and perform error correction.

The output of the FEC decoding process is then split into segments. The cyclic redundancy check information within each segment is then compared to determine whether a particular segment was received in error. If this is the case, then a request is made to retransmit the erroneously received segment.

Eventually, the received segments are reassembled into a complete network layer frame.

The protocol converters at both the transmitter and receiver ends may also dynamically adjust the size of the segments based upon an observed received segment error rate in order to optimize overall throughput. For example, at the receiver side, a segment with the bad cyclic redundancy check (CRC) is discarded and counted as a "bad" segment. By keeping track of the sequence numbers of the received segments, the receiver can determine that a particular segment, namely a segment with a sequence number between the last good segment and the next good segment is missing. The receiver then can explicitly request retransmission of the bad segment by sequence number. This so-called selective reject feature permits both the receiver and the transmitter to know the number of frames received in error from the tally of selectively rejected segments.

From the count of the number of frames sent and the number of selective reject orders received over a given radio channel, the transmitter can then dynamically adjust the size of later transmitted segments for that channel. Preferably, the segment size is adjusted based upon a formula that depends upon the ratio of total number of data bits transferred to the number of bits successfully used to carry information.

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By performing forward error correction on a group of segments, rather than on individual segments, the channel bandwidth allocations can thus remain optimized.

The invention is particularly advantageous in an environment which requires the use of packet-oriented protocols such as TCP/IP. Because the number of channels needed to carry a single data stream can be varied efficiently, burst rates can also be efficiently adapted.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis being instead placed upon illustrating the principles of the invention.

Fig. 1 is a block diagram of a system in which a portable data processing device uses a protocol converter according to the invention to connect to a network.

Fig. 2 is a more detailed diagraming depicting the architecture of the protocol converter and multichannel transceiver.

Fig. 3 is a diagram illustrating how network layer frames are divided into segments by a protocol converter located at a transmitter.

Fig. 4 is a detailed diagram of an individual segment and how multiple segments are assembled into a forward error correction block.

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Fig. 5 is a diagram illustrating how a protocol converter at a receiver reassembles the network layer frames.

Fig. 6 is a series of steps performed by a protocol converter located at the transmitter to implement the invention.

Fig. 7 is a continuation of the diagram of Fig. 6.

Fig. 8 is a diagram of the steps performed by a protocol converter located at a receiver to implement the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Turning attention now to the drawings more particularly, Fig. 1 is a block diagram of a system 10 for providing high speed data communication service according to the invention. The system 10 consists of a remote subscriber unit 20, multiple bidirectional communication links 30, and a local or service provider unit 40.

The subscriber unit connects to terminal equipment 12, such as a portable or laptop computer, hand held personal digital assistant (PDA), or the like. The subscriber unit 20 includes a protocol converter 25 which in turn provides data to a multichannel digital transceiver 26 and antenna 27.

The protocol converter 25 receives data from the computer 20, and together with appropriate hardware and/or software, converts it to a format suitable for transmission such as in accordance with known communication standards.

The protocol converter 25 implements an intermediate protocol layer that coverts the data to a format appropriate for use by the multichannel transceiver 26 according to the invention. As will be

described in much grater detail below, at a network layer, the data provided by the protocol converter 25 is preferably formatted in a manner consistent with suitable network communication protocols, such as TCP/IP, to permit the terminal equipment 12 to connect to other computers over networks such as the Internet. This description of the protocol converter 25 and protocols is exemplary only and it should be understood that other network layer protocols can be used.

The multichannel digital transceiver 26 provides access to one or more physical communication links such as the illustrated radio channels 30. The physical links are preferably further encoded using known digital multiplexing techniques such as Code Division Multiple Access (CDMA) to provide multiple traffic on a given radio channel 30 or sub-channels 31. It should be understood that other wireless communication protocols may also be used to advantage with the invention.

The communications channels may be implemented by providing multiple coded sub-channels 31 on a single wide bandwidth CDMA carrier channel 30 such as having a 1.25 MegaHertz bandwidth. The individual channels are then defined by unique CDMA codes. Alternatively, the multiple channels 31 may be provided by single channel physical communication media such as provided by other wireless communication protocols. What is important is that the sub-channels 31 may be adversely effected by significant bit error rates that are unique to each radio channel 30.

The service provider equipment 40 includes an antenna 42, a multichannel transceiver 46, a protocol converter 45, and other interface equipment 48 such as modems, bridges, gateways, routers, and the like, which

are needed to provide connections to the Internet 49 or other network.

At the service provider 40, the multichannel transceiver 46 provides functions analogous to the multichannel transceiver 26 of the subscriber unit, but in an inverse fashion. The same is true of the protocol converter 45, that is, it provides inverse functionality to the protocol converter 25 in the subscriber unit 20. Data is accepted from the protocol converter 45 in the TCP/IP frame format and then communicated to the Internet 49. It should be understood that the configuration of the remaining equipment 40 may take any number of forms such as a local area networks, multiple dial up connections, T1 carrier connection equipment, or other high speed communication links to the Internet 49.

Turning attention now to the protocol converters 25 and 45 more particularly, they provide bandwidth management functionality 29 implemented between a physical layer such as provided by the CDMA protocol in use with the multichannel transceivers 26 and a network layer protocol such as TCP/IP providing connections between the terminal equipment 22 and the network 49.

The bandwidth management function 29 performs a number of tasks in order to keep both the physical layer and network layer connections properly maintained over multiple communication links 30. For example, certain physical layer connections may expect to receive a continuous stream of synchronous data bits regardless of whether terminal equipment at either end actually has data to transmit. Such functions may also include rate adaption, bonding of multiple channels on the links, spoofing, radio channel setup and teardown. The details for implementing a protocol converter specifically for ISDN terminal equipment 22 and Code Division Multiple

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Access (CDMA) modulation techniques in use by the multichannel transceiver 26 are more specifically described in a pending patent application by Thomas E. Gorsuch and Carlo Amalfitano, entitled "A Protocol Conversion and Bandwidth Reduction Technique Providing Multiple nB+D ISDN Basic Rate Interface Links Over A Wireless Code Division Multiple Access Communication System," filed December 17, 1997 and given serial number 08/992,759, which is assigned to Tantivy Communications, Inc., the assignee of the present application, and which application is hereby incorporated by reference.

The present invention is more particularly concerned with the techniques used by the protocol converters 25 and 45 for formatting the data to be transmitted over implementing multiple logical sub-channels 31-1, 31-2, ..., 31-n each of the multiple radio channels 30 in order to improve the effective throughput rate between a transmitter and a receiver in a bit error rate prone environment. It should be understood in the following discussion that the connections discussed herein are bidirectional, and that a "transmitter" may either be the subscriber unit 22 or the service provider unit 40.

In addition, an "error" as described herein is a bit error perceived at the higher layer such as the network layer. The invention only strives to improve the overall system level bit error rate, and does not attempt to guarantee absolute data integrity.

Turning attention now to Fig. 2, there is shown in more detail a block diagram of a forward link and reverse link implemented according to the invention, more particularly showing the protocol converter 25 and multichannel transceiver 26 associated with the subscriber side unit and the multichannel transceiver 46

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and protocol converter 44 associated with the service provider unit 40.

Beginning with the lower portion of the diagram in the reverse link direction, that is, in the direction of transmission from the subscriber unit 20 to the service provider unit 40, the reverse link protocol converter 25 consists of a buffer 61, segment framer 62, and forward error correction (FEC) unit 63. The multichannel transceiver 26 consists of a pseudonoise (PN) code generator 64, modulator 65, and radio frequency (RF) up converter 66. The buffer 61 receives input data in a manner which will be described in more detail further. Segment framer 62 arranges data received from the buffer in an appropriate format to be fed to the FEC unit 63. The FEC unit 63 applies a forward error correction algorithm to the data using a known error correction technique such as Reed Solomon, Turbo Codes, or other codes.

The transceiver 66, in this instance using it as a transmitter, spreads the resulting data by the PN sequence, modulates the PN spread data with appropriate channel coding per the assigned sub-channels 31, and the up converts the result to the desired radio frequency.

On the receive side of the reverse link, that is, at the service provider 40 side, the transceiver 44 performs a receiver function. In this instance, the RF down converter 71 feeds multiple receiving units that each include an equalizer 72, a PN code despreader 73, and demodulator 74. Each demodulated output is provided to a protocol converter block that includes an FEC decoder 75, an inverse segment framer 76, and buffer 77. A controller 78 may be used to control and/or implement each of the protocol converter functions as described in further detail below.

In the preferred embodiment, the FEC decoder 75 makes use of a so-called trellis decoder. Because a trellis decoder is a type of decoder which compares multiple bits in groups to arrive at an estimate of the correct received bits, when a trellis decoder does produce errors, they tend to occur in groups.

The analogous functions are provided on the forward link. In this instance, the protocol converter 45 receives input data, processing it through a buffer 61, segment framer 62, and FEC unit 63. The transceiver 46 performs a transmitting function over multiple sub-channels 31, including multiple spreaders 64, modulators 65, and RF up converters 66.

On the receiver side of the forward link, the inverse process is provided by an RF down converter 71, equalizer 72, despreader 73, and channel separator 79 and demodulator 74 for each channel. Forward error correction unit 75, segment framer 76, and buffer 77 complete the implementation of the protocol converter 25.

Turning attention now more particularly to Fig. 3, the operations of an exemplary protocol converter 25, at the transmit side will briefly described. As shown, an input frame 80 as received from the network layer is relatively large, such as for example 1480 bits long, in the case of the TCP/IP protocol.

The input frame 80 is first divided into a set of smaller pieces or segments 81-1, 81-2. The size of the individual segments 81 are chosen based upon an optimum segment length determined for each of the channels 30. For example, a bandwidth management function may make only a certain number of sub-channels 31 available at any time. A subset of the available sub-channels 31 is selected, and then the optimum number of bits for each

segment intended to be transmitted over respective one of the sub-channels, is then chosen. Thus as illustrated in the figure, a given frame 80 may be divided into segments associated with four sub-channels 31. At a later time, there may be nine sub-channels 31 available for a frame, with different optimum segment sizes for the segment 81-2.

An optimum subframe size can thus be determined for each channel 30 for these parameters described in our previously referenced co-pending patent application. In the preferred embodiment, for example, this is set equal to

$$X = -H + \sqrt{\left(X_{current} + H_{current} \right) * H / R}$$

where H is the frame overhead in bytes, including any shared frame synchronization flags (7e) between subframes, X_c is a current number of data bytes assigned to a subframe, H_c is the current frame overhead, and R is the observed subframe error ratio.

In the preferred embodiment, the segment size is the same for segments 81 associated with each associated radio channel 30 and frame 80 to minimize overhead, although that is not an absolute requirement.

After the frame 80 is divided into segments 81, each of the segments 81 has additional information appended to it. For example, each of the segments 81 consists of at least a position identifier 82a and an integrity check sum such as in the form of a cyclic redundancy check (CRC) 82b. Position identifier 82a serves to indicate the position of each segment 81 within its associated large frame 80. The integrity check sum 82b serves to permit the receiver to determine whether particular segments 81 are received in error.

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The segments 81 are then further prepared for transmission over each sub-channel 31. In particular, the segments 81 are next grouped into blocks 86. The number of segments in each block 86 is selected to a convenient number depending upon the forward error correction 63, 75 to be applied. For example, in a preferred embodiment, forward error correction block 86 consists of a sufficient number of segments 81 to total 1331 bits. If the FEC algorithm being applied is a one-third rate code, this results in a FEC block 86 length of 4096 bits. Finally, the FEC block 86 is divided among the sub-channels 31 allocated to the particular connection and transmitted.

Fig. 4 is a more detailed view of the format of a segment 81. Segment 81 consists of a number of fields, including the position field 82a and the CRC field 82b previously mentioned. A number of other fields are also evident in the exemplary segment 81. In particular, there is a data field 82c which carries the associated source data taken from the input large frame 80. This data field 82c is a variable size and can be changed according to optimized parameters as specified by an observed error rate. In a preferred embodiment, the number of data bits may vary from 2 up to 512 in a given segment 81 depending upon observed error rates. As previously mentioned, all segments across a given input frame 80 are selected to be equal in size, e.g., they have an equal sized data field 82c.

Furthermore, while a given input frame will be transmitted over multiple sub-channels 31, it will only be divided into segments which are to be transmitted over a given radio channel 30.

In addition, a frame offset field 82d may be used to identify which of a number of frames each segment 81

pertains to. This frame offset field is of particular use because of latencies involved in the system. In particular, segments 81 are not necessarily guaranteed to arrive at the receiver in the same order as they were transmitted. Furthermore, if particular segments 81 are received in error, it may be necessary to request retransmission. Therefore, it is possible that segments 81 associated with more than one block need to be operated upon at the receiver at a given time. The frame offset field 82d therefore permits the receiver to distinguish which large frame 80 each segment 81 belongs to.

A code sequence field 82e may be used to identify a sequence number related to each sub-channel 31 at the beginning of each frame. This permits lower order channel processing to route segments 81 more efficiently.

Finally, a message data field 82f may be used to indicate whether the segment 81 contains source data, i.e., active traffic data, or control information for the intended recipient.

Fig. 5 illustrates the operations performed at the receiver side. Data bits received from the multiple sub-channels 31 are first collected in order to reconstruct the FEC block 86.

Next, the FEC algorithm is applied to detect and correct one or more bits using error correction coding. The resulting information is split into segments 81 using the known segment size. The segments 81 are then examined and the position field 82 is used to reconstruct the large frame 80. Any segments 81 that are missing can thus be detected by comparing the received position fields 82a. If a sequence position field in a frame in a particular position or particular

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sequence number 82e is missing, it is assumed that the associated segment 81 was not received. It should be understood that appropriate buffering of data and segments 81 is typically required in order to properly receive the segments 81 and determine if any are missing. The buffer size will depend upon the transmission rates, number of sub-channels 31, and propagation delays in effect.

Upon detection of a missing segment 81, retransmission of the missing segment 81 is requested by the receiver. At this point, the transmitter re-performs transmission of the missing segment 81. Once all of the segments 81 in a particular large frame 80 are received, the position information 82a can then be used to arrange the data from the segments 81 in the proper order to reconstruct the original large frame 80.

At this point, if any piece of the large frame 80 is still miss such as when an end of frame command is encountered, retransmission of the corresponding segment 81 can be requested at the indicated position, specifying a length for the missing piece.

Because of the use of both the position field 82a and sequence field 82e, both the transmitter and receiver know the ratio of the number of subframes 81 received with errors to the number of subframes 81 received without errors. Also, the receiver and transmitter know the average subframe length for each channel.

Fig. 6 is a detailed flow diagram of a set of operations performed by the transmitter in order to implement the invention. In a first state 100, the large frame 80 is obtained from an upper communication layer such as the network layer. In a next state 102, the transmitter computes an optimum segment size from

past observations of frame error rates on the individual sub-channels 81, preferably calculating an optimum segment size for all communication channels available.

In a next state 104, the network layer frame 80 is divided into an appropriate number of segments 81 according to the optimum size for each associated sub-channel available. This division is also based upon the available sub-channel estimated throughput. A list of segments is then created.

In a next state 106, a position identifier and a cyclic redundancy check (CRC) code is added to each segment 81. The position identifier offset within the large frame 80, as described above, is then added to allow correct positioning of the segment 81 when reconstructing the frame 80 at the receiver end.

Next, an FEC block 86 is assembled from the multiple segments 81. Following that, in state 108, the FEC block 86 is demultiplexed and the bits in the FEC block are assigned to respective ones of the multiple sub-channels 31.

When the transmitter receives a retransmission request for a segment 81 missing at the receiver, a state 110 is entered in which an optimum segment size is computed from the observed frame averages for the available communications sub-channels 31. The segment list is then used to requeue the segment for retransmission in state 112. Processing then continues at state 108 for retransmission of the missing segment 81.

Fig. 7 shows the remainder of the steps performed at the transmitter. In a state 114, a channel-related sequence number is added to each segment 81. In a next state 116, segment separators such as flags in the form "7E" are inserted into the segments. In addition, any

zero insertion such as mandatory setting of a data bit to a 1 after a sequence of five zeros, is performed. Other synchronization, separation, and coding techniques may require that bits be inserted into the segments 81 at this point. For example, a given channel 30 may make use of convolutional coding as specified by the IS-95 standard, and if so, this is performed here.

In a next state 118, the segments 81 are sent over the available channels 31. Non-data frames such as logical start, logical end and other control frames may be inserted at this point as well.

In a final state 120, the transmitter operates on any segment retransmission requests or positive acknowledgments of a large frame being received correctly. Another frame transmission may be initiated, for example, at this point before completion of a frame in transit.

Fig. 8 shows a detailed sequence of the steps performed at the receiver. In a first state 200, a received FEC frame 86 is assembled from the bit streams taken from multiple sub-channels 31. In the next state 201, the FEC frame is then split into segments 81 according to the current segment size.

In the next state 202, the subframes 81 are examined. Any segment with a good CRC is passed to the next following state 203. Any other received segment 81 with a bad CRC is discarded.

Continuing with state 203, the receiver determines any missing sequence numbers. The receiver then requests retransmission of segments 81 for the missing pieces based upon sequence number by sending back a retransmission request to the transmitter.

In a next state 204, from the position identifier and the known length of each original large frame 80,

the receiver attempts to rebuild the original frame 80. In state 206, if any pieces of the frame 80 are still missing after the retransmission requests are all processed, accommodating the fact that a retransmission request itself may be lost, the receiver requests the missing portion of the large frame 80 by position and size.

In state 208, once the frame 80 is completely received, a positive acknowledgment is returned back to the transmitter.

It can now be understood that by applying the sub-channel segmentation step first, prior to error correction encoding, the full benefit of the error correction code is obtained while minimizing the amount of data that needs to be re-transmitted. In particular, because bit errors in the output of the trellis-implemented FEC decoder 75 tend to occur together, they will also therefore tend to affect a single segment 81.

EQUIVALENTS

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described specifically herein. Such equivalents are intended to be encompassed in the scope of the claims.

SDOCID: <WO___0052831A2_I_>

CLAIMS

What is claimed is:

1. A method for communication of data between a transmitter and a receiver over one or more communication channels, the data being provided in a frame, the method comprising the steps of:

at the transmitter:

(a) dividing the frame into segments according to an optimum segment size;

(b) combining multiple segments into a segment block;

(c) applying a forward error correction encoding process to the segment block to produce a forward error correction block;

(d) sending the forward error correction block over a communication channel;

at the receiver:

(e) applying a forward error correction decoding process on the forward error correction block to produce a received block;

(f) dividing the received block into segments;

(g) determining if any segment was received in error; and

(h) requesting retransmission only of the segment received in error.

2. A method as in claim 1 additionally comprising the step of, at the transmitter:

(i) inserting a checksum into the segments to enable identification of erroneously received segments at the receiver.

3NSDOCID: <WO 0052831A2 >

3. A method as in claim 1 wherein step (b) additionally comprises the step of, at the transmitter:

(j) inserting a position number into the segments to identify a position of the segment within the frame.

4. A method as in claim 1 wherein step (d) additionally comprises sending the forward error correction block over multiple distinct communication channels.

5. A method as in claim 1 additionally comprising the steps of, at the receiver:

(k) determining the number of segments received at the receiver in error; and

(l) determining the optimum segment size for the communication channel based upon the determined number of segments received in error which were attempted to be communicated over that channel.

6. A method as in claim 5 wherein steps (k) and (l) additionally comprise determining an error rate in each channel and an optimum number of segments for each channel individually.

7. A method as in claim 5 wherein step (k) determines the number of segments received in error at the receiver by counting the number of selective reject orders made to the transmitter.

DOCID: <WO___0052831A2_I_>

8. A method as in claim 1 wherein step (k) determines an optimum number of frames according to a ratio of a number of segments received in error to a number of segments received correctly.

9. A method as in claim 1 wherein step (k) additionally comprises the step of determining an adjusted number of data bytes in a frame, X, from the formula:

$$X = -H + \sqrt{ (X_{current} + H_{current}) * H / R }$$

where $X_{current}$ is the present number of data bytes in a frame, $H_{current}$ is the present frame overhead in bytes,, H is the new overhead for the frame in bytes, and R is a ratio of segments received in error to segments received correctly.

10. A method for providing wireless communication of digital signals, the digital signals being communicated between a plurality of wireless subscriber units and a base station, the digital signals being communicated using at least one radio frequency channel via Code Division Multiple Access (CDMA) modulated radio signals, the digital signals also having a given nominal data rate, the method comprising the steps of:

(a) making available a plurality of sub-channels within each CDMA radio channel, wherein a data rate of each sub-channel is less than the nominal data rate of the digital signals;

(b) establishing a network layer session between terminal equipment connected to the subscriber unit through the base station to other terminal equipment connected to the base station; and

(c) during the network layer session, allocating available sub-channels on an as-needed basis, with the number of sub-channels allocated thereby changing during the duration of a given session;

(d) dividing a network layer frame into segments according to optimum segment sizes;

(e) combining multiple segments into a segment block;

(f) applying a forward error correction encoding process to the segment block to produce a forward error correction bock;

(g) at a receiver, decoding the forward error correction block and divides it back into segments; and

(h) requesting retransmission only of a segment received in error.

11. A method as in claim 10 additionally comprising the step of:

(i) determining an optimum segment size for the sub-channels based upon a determined number of segments received in error which were attempted to be communicated over the sub-channels.

12. A method as in claim 10 wherein step (i) additionally comprises dynamically adjusting the

SDOCID: <WO___0052831A2_I_>

frame size of a channel to optimize the effective throughput of the overall system based upon the ratio of actual data transferred to the number of bits actually used to carry information, including frame overhead and retransmissions.

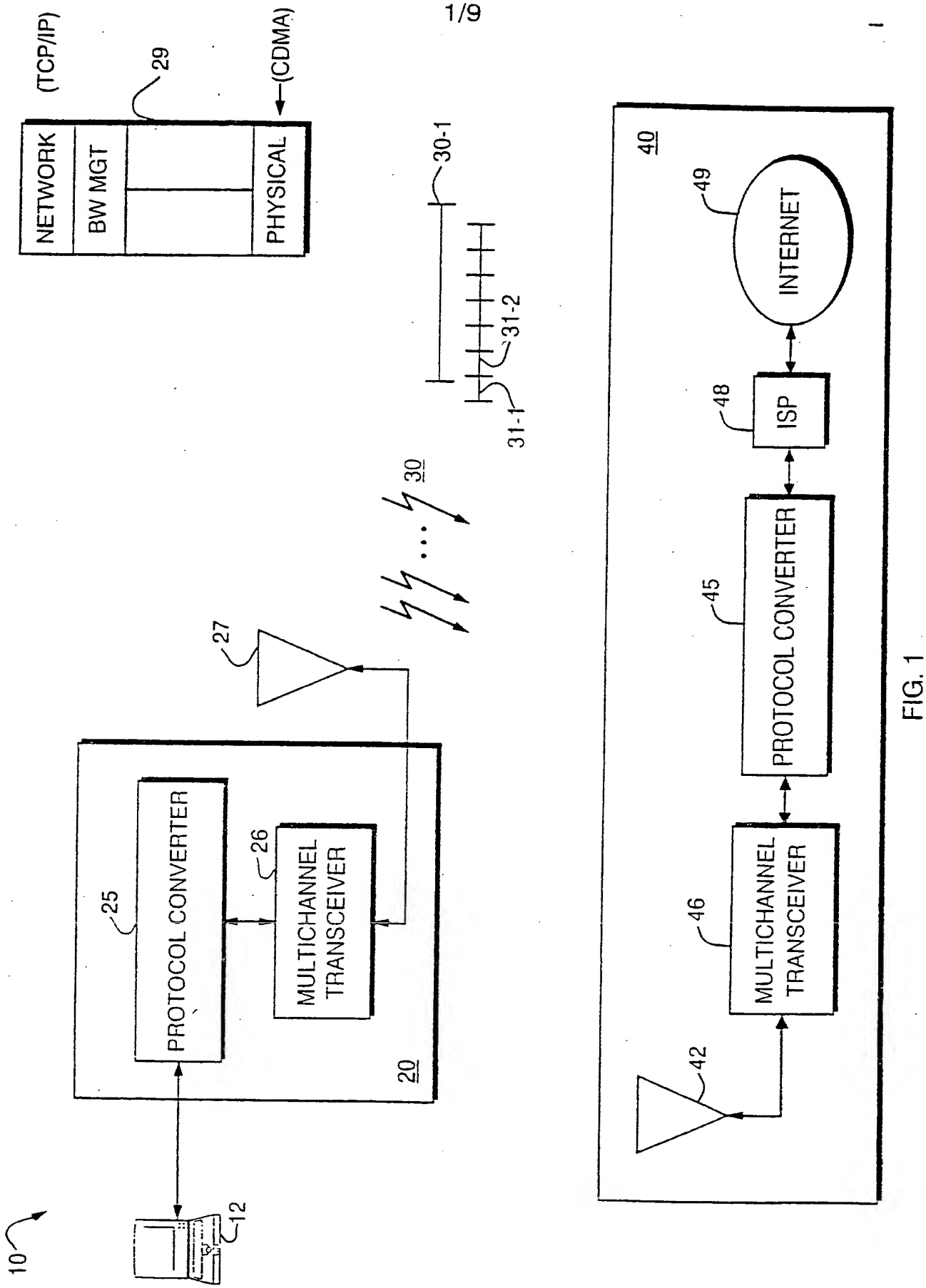

(TCP/IP)
29
(CDMA)
NETWORK
BW MGT
PHYSICAL
30-1
31-2
31-1
30
27
PROTOCOL CONVERTER
25
26
MULTICHANNEL TRANSCEIVER
20
10
12
40
49
INTERNET
48
ISP
PROTOCOL CONVERTER
45
MULTICHANNEL TRANSCEIVER
46
42

FIG. 1

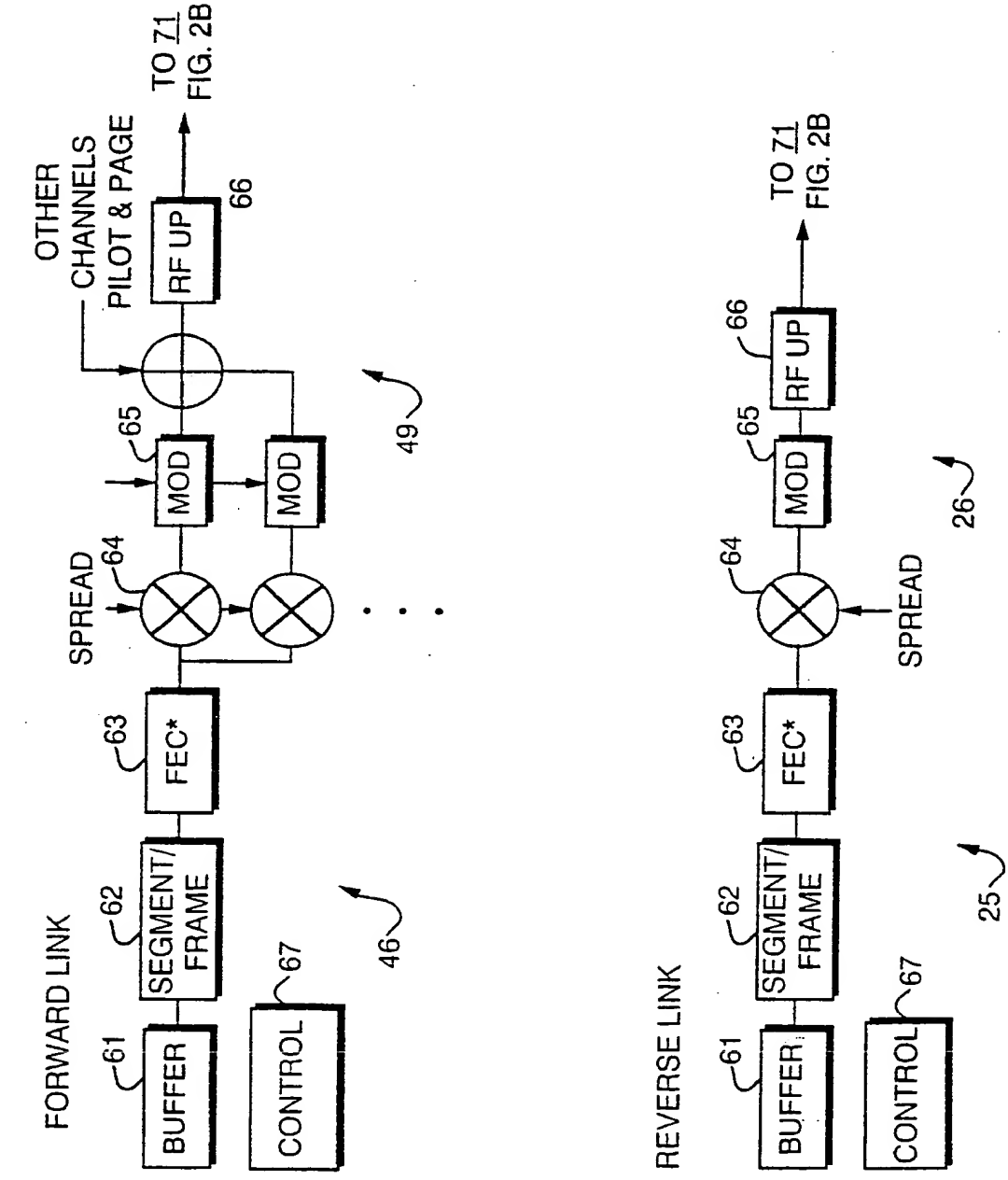

FORWARD LINK
BUFFER
61
SEGMENT/ FRAME
62
FEC*
63
SPREAD
64
MOD
65
MOD
RF UP
66
OTHER CHANNELS PILOT & PAGE
TO 71 FIG. 2B
CONTROL
67
46
49
REVERSE LINK
BUFFER
61
SEGMENT/ FRAME
62
FEC*
63
SPREAD
64
MOD
65
RF UP
66
TO 71 FIG. 2B
CONTROL
67
25
26

FIG. 2A

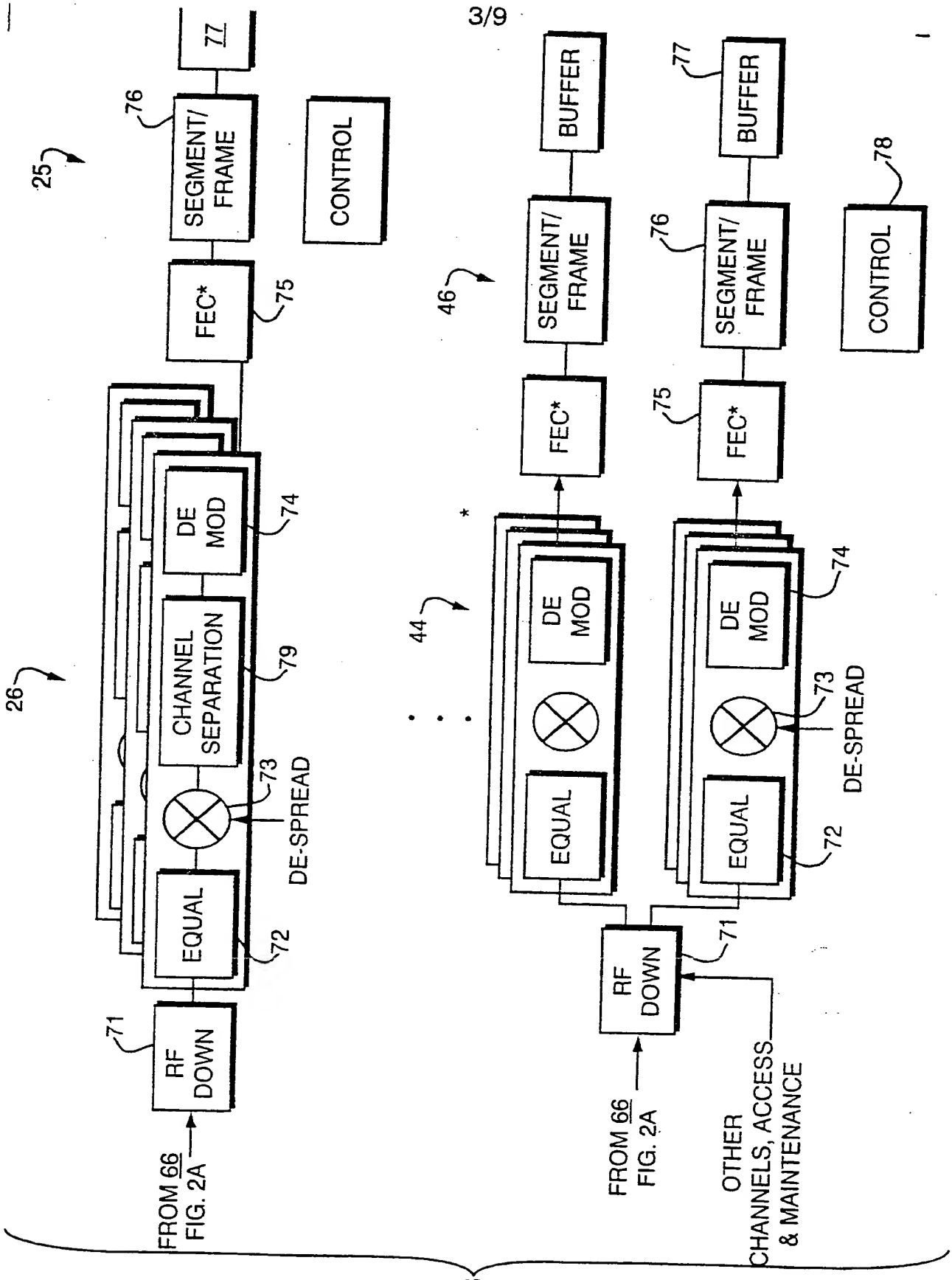


FIG. 2B

SDOCID: <WO___0052831A2_I_>

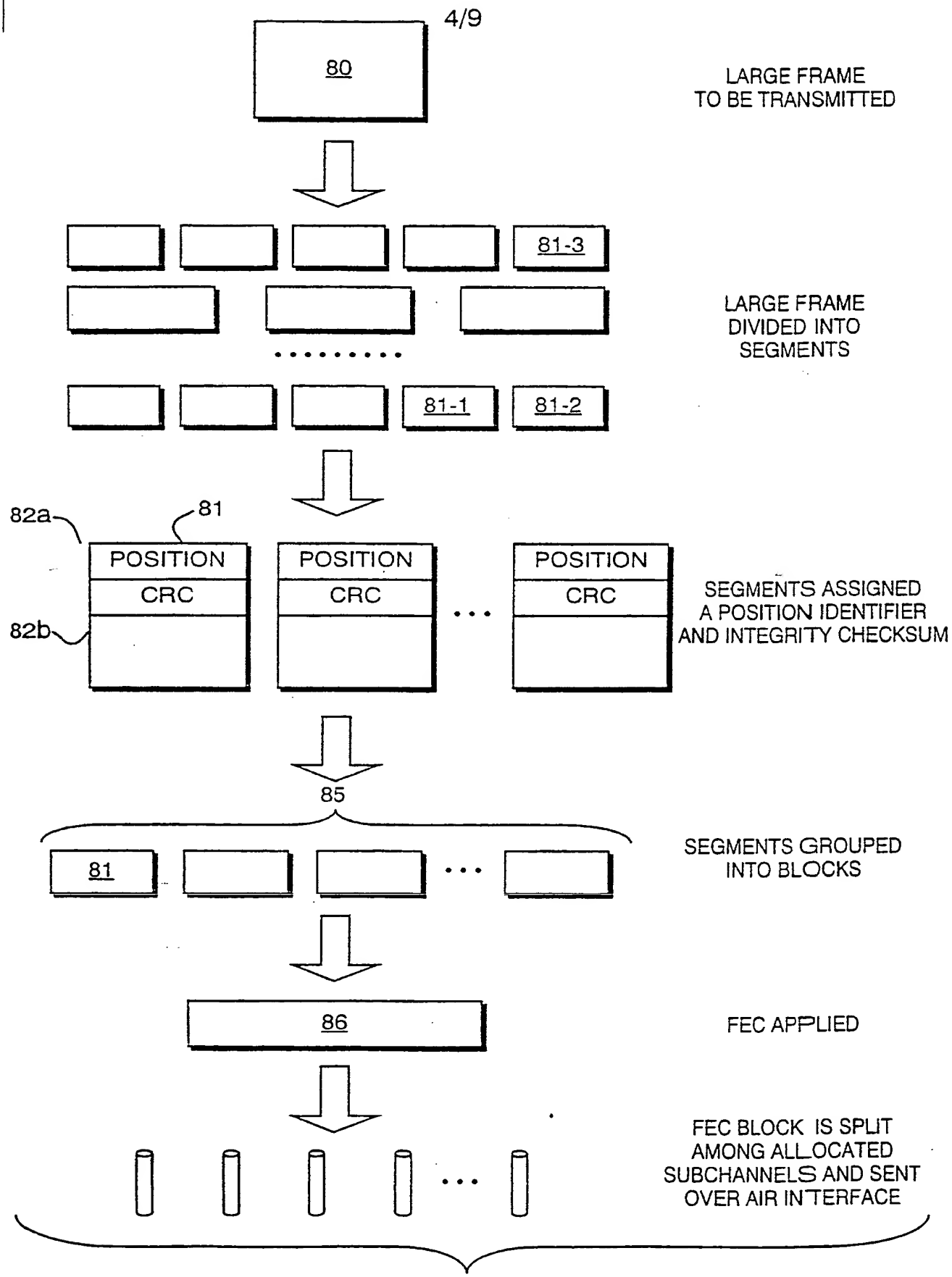

80
LARGE FRAME TO BE TRANSMITTED
81-3
LARGE FRAME DIVIDED INTO SEGMENTS
81-1
81-2
82a
81
POSITION
CRC
82b
SEGMENTS ASSIGNED A POSITION IDENTIFIER AND INTEGRITY CHECKSUM
85
81
SEGMENTS GROUPED INTO BLOCKS
86
FEC APPLIED
FEC BLOCK IS SPLIT AMONG ALLOCATED SUBCHANNELS AND SENT OVER AIR INTERFACE

FIG. 3

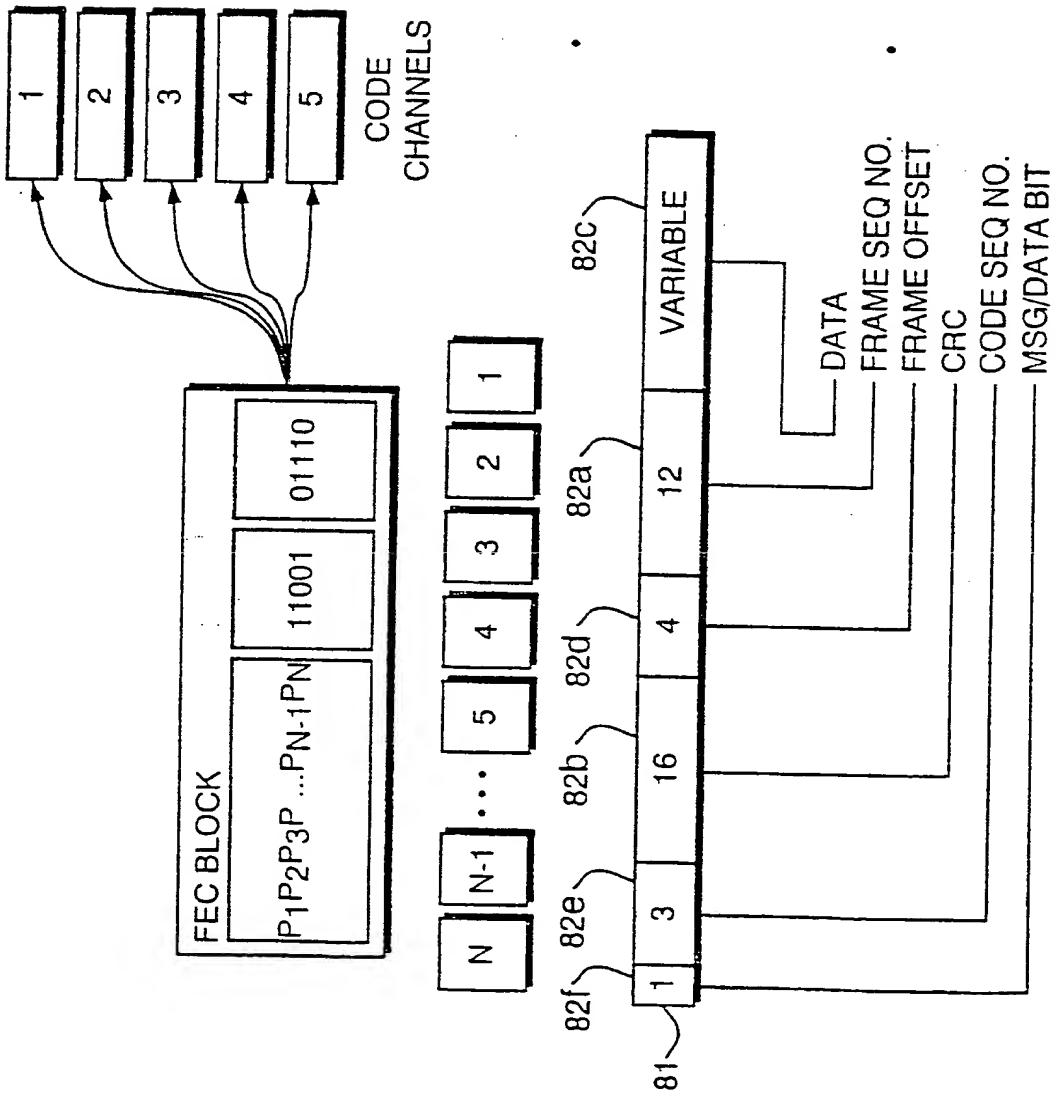


FIG. 4

SDOCID: <WO___0052831A2_I_>

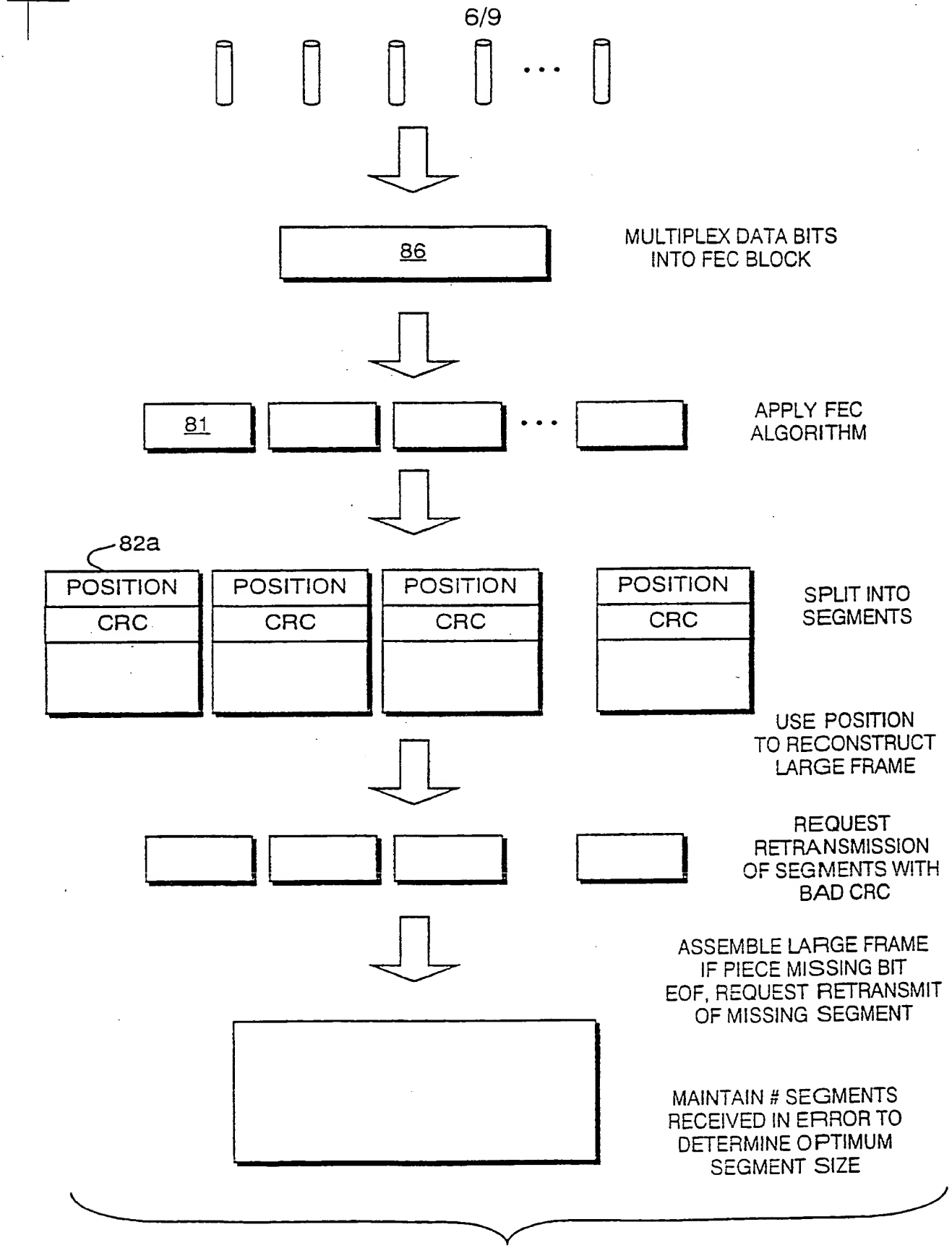

86
MULTIPLEX DATA BITS INTO FEC BLOCK
81
APPLY FEC ALGORITHM
82a
POSITION
CRC
SPLIT INTO SEGMENTS
USE POSITION TO RECONSTRUCT LARGE FRAME
REQUEST RETRANSMISSION OF SEGMENTS WITH BAD CRC
ASSEMBLE LARGE FRAME IF PIECE MISSING BIT EOF, REQUEST RETRANSMIT OF MISSING SEGMENT
MAINTAIN # SEGMENTS RECEIVED IN ERROR TO DETERMINE OPTIMUM SEGMENT SIZE

FIG. 5

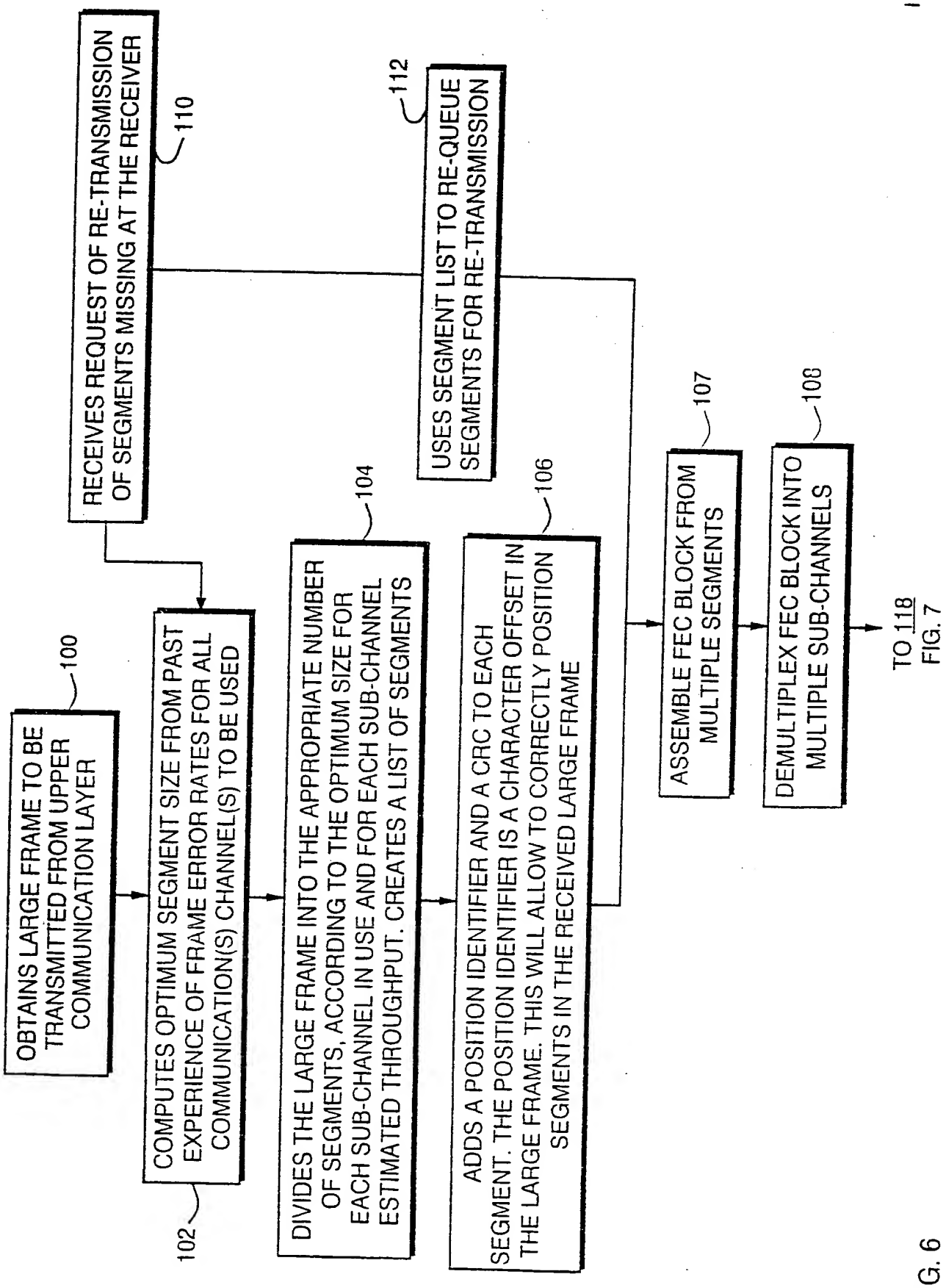

OBTAINS LARGE FRAME TO BE TRANSMITTED FROM UPPER COMMUNICATION LAYER
100
COMPUTES OPTIMUM SEGMENT SIZE FROM PAST EXPERIENCE OF FRAME ERROR RATES FOR ALL COMMUNICATION(S) CHANNEL(S) TO BE USED
102
DIVIDES THE LARGE FRAME INTO THE APPROPRIATE NUMBER OF SEGMENTS, ACCORDING TO THE OPTIMUM SIZE FOR EACH SUB-CHANNEL IN USE AND FOR EACH SUB-CHANNEL ESTIMATED THROUGHPUT. CREATES A LIST OF SEGMENTS
104
ADDS A POSITION IDENTIFIER AND A CRC TO EACH SEGMENT. THE POSITION IDENTIFIER IS A CHARACTER OFFSET IN THE LARGE FRAME. THIS WILL ALLOW TO CORRECTLY POSITION SEGMENTS IN THE RECEIVED LARGE FRAME
106
ASSEMBLE FEC BLOCK FROM MULTIPLE SEGMENTS
107
DEMULTIPLEX FEC BLOCK INTO MULTIPLE SUB-CHANNELS
108
TO 118
FIG. 7
RECEIVES REQUEST OF RE-TRANSMISSION OF SEGMENTS MISSING AT THE RECEIVER
110
USES SEGMENT LIST TO RE-QUEUE SEGMENTS FOR RE-TRANSMISSION
112

FIG. 6

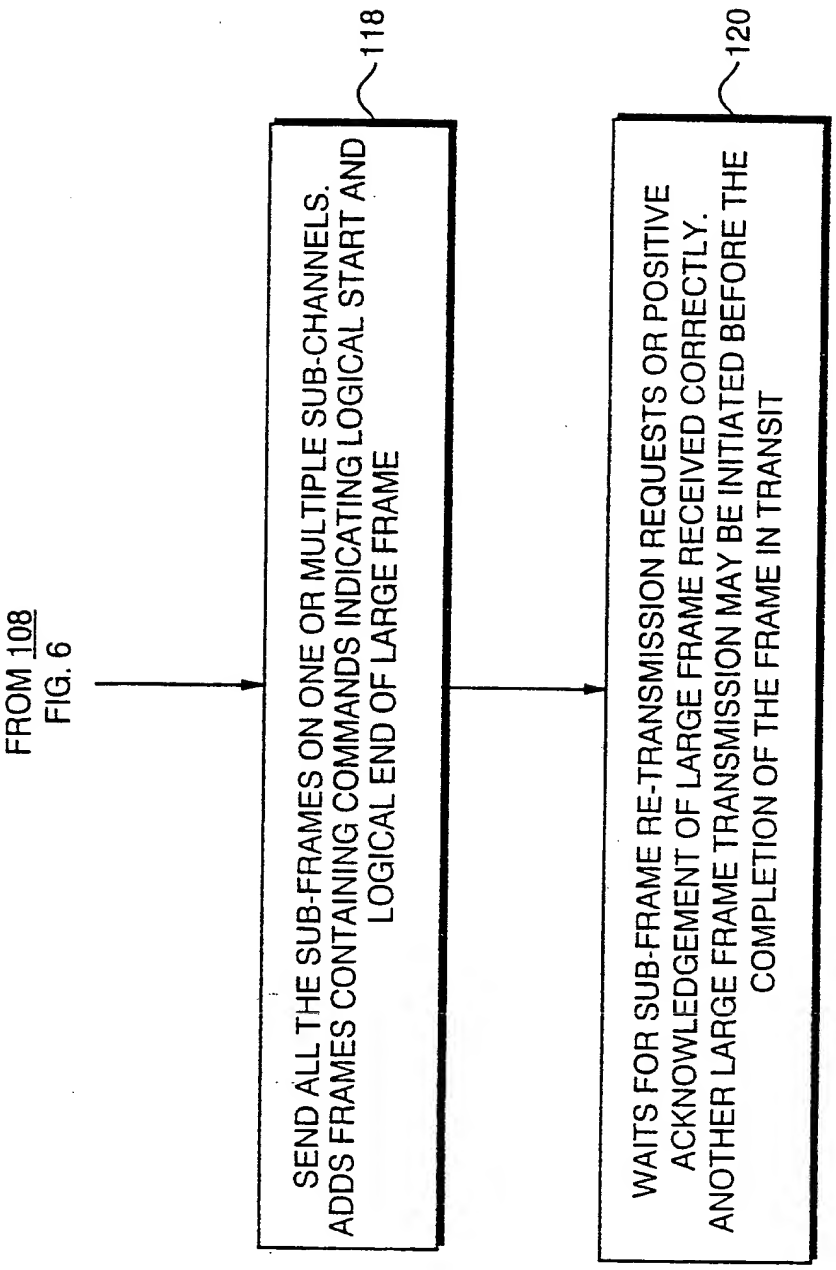

FROM 108
FIG. 6
SEND ALL THE SUB-FRAMES ON ONE OR MULTIPLE SUB-CHANNELS. ADDS FRAMES CONTAINING COMMANDS INDICATING LOGICAL START AND LOGICAL END OF LARGE FRAME
118
WAITS FOR SUB-FRAME RE-TRANSMISSION REQUESTS OR POSITIVE ACKNOWLEDGEMENT OF LARGE FRAME RECEIVED CORRECTLY. ANOTHER LARGE FRAME TRANSMISSION MAY BE INITIATED BEFORE THE COMPLETION OF THE FRAME IN TRANSIT
120

FIG. 7

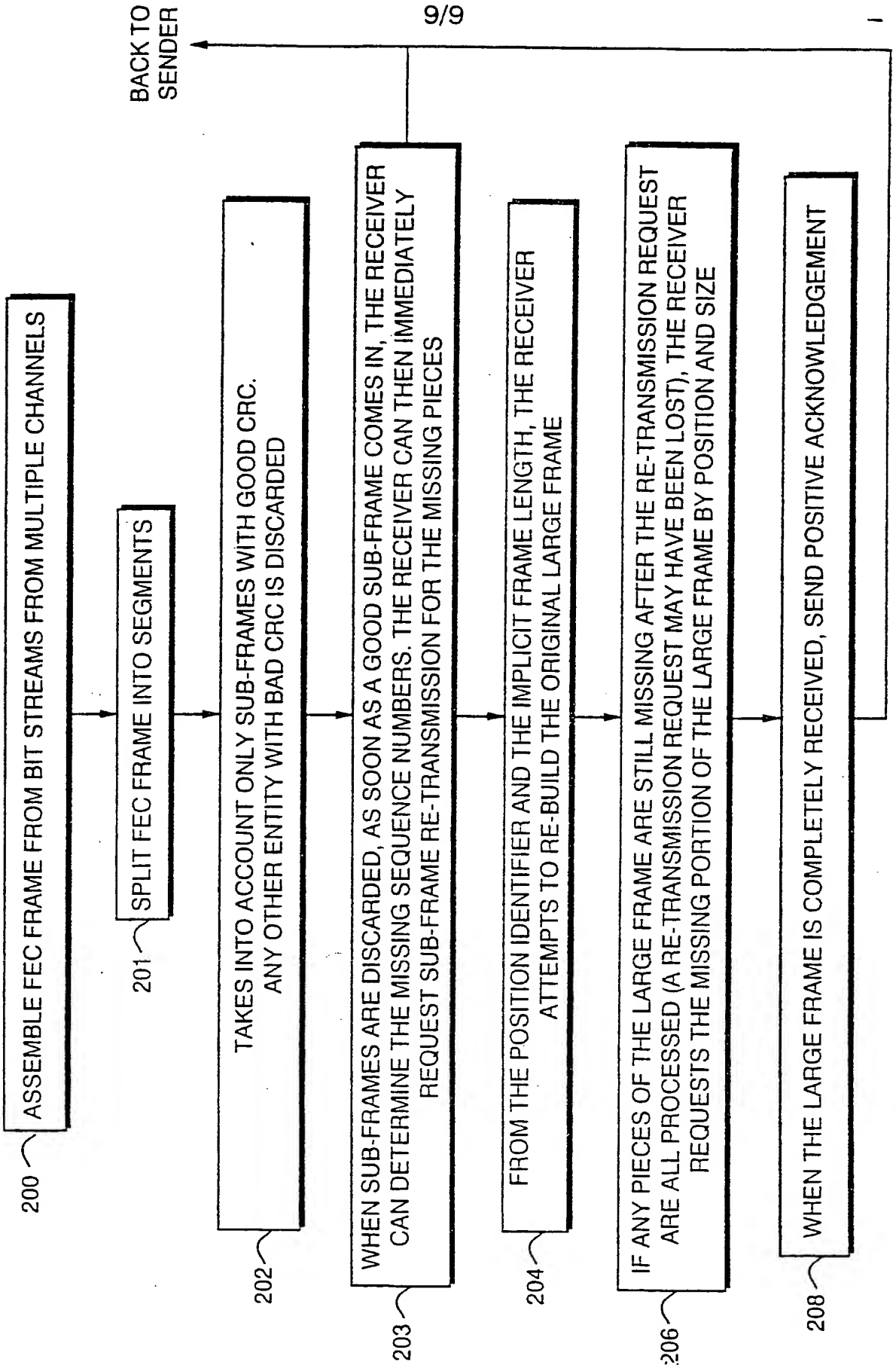
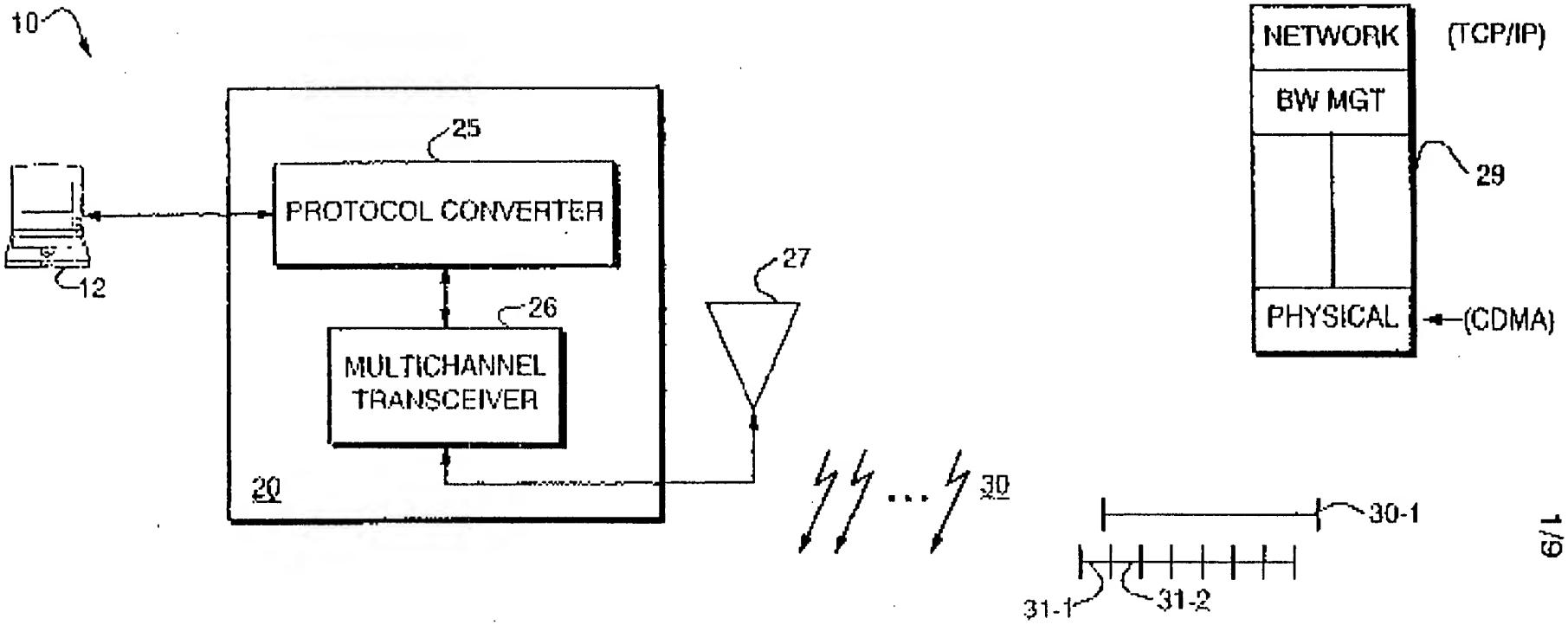

BACK TO SENDER
ASSEMBLE FEC FRAME FROM BIT STREAMS FROM MULTIPLE CHANNELS
200
SPLIT FEC FRAME INTO SEGMENTS
201
TAKES INTO ACCOUNT ONLY SUB-FRAMES WITH GOOD CRC. ANY OTHER ENTITY WITH BAD CRC IS DISCARDED
202
WHEN SUB-FRAMES ARE DISCARDED, AS SOON AS A GOOD SUB-FRAME COMES IN, THE RECEIVER CAN DETERMINE THE MISSING SEQUENCE NUMBERS. THE RECEIVER CAN THEN IMMEDIATELY REQUEST SUB-FRAME RE-TRANSMISSION FOR THE MISSING PIECES
203
FROM THE POSITION IDENTIFIER AND THE IMPLICIT FRAME LENGTH, THE RECEIVER ATTEMPTS TO RE-BUILD THE ORIGINAL LARGE FRAME
204
IF ANY PIECES OF THE LARGE FRAME ARE STILL MISSING AFTER THE RE-TRANSMISSION REQUEST ARE ALL PROCESSED (A RE-TRANSMISSION REQUEST MAY HAVE BEEN LOST), THE RECEIVER REQUESTS THE MISSING PORTION OF THE LARGE FRAME BY POSITION AND SIZE
206
WHEN THE LARGE FRAME IS COMPLETELY RECEIVED, SEND POSITIVE ACKNOWLEDGEMENT
208

FIG. 8


10
NETWORK
(TCP/IP)
BW MGT
29
PHYSICAL
(CDMA)
25
PROTOCOL CONVERTER
12
26
MULTICHANNEL TRANSCEIVER
27
20
30
30-1
31-1
31-2

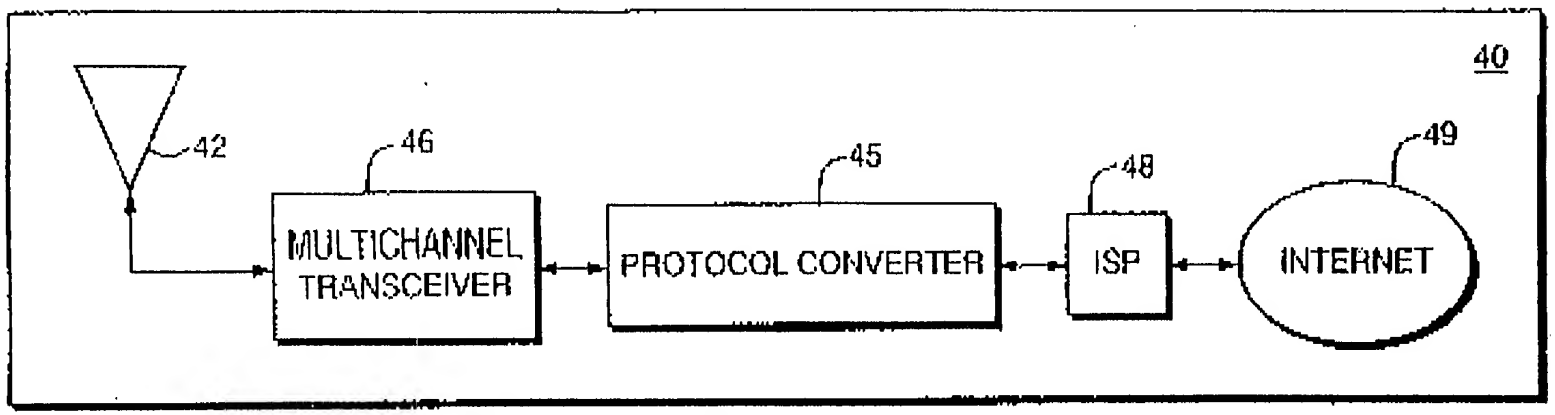

40
42
46
MULTICHANNEL TRANSCEIVER
45
PROTOCOL CONVERTER
48
ISP
49
INTERNET

FIG. 1

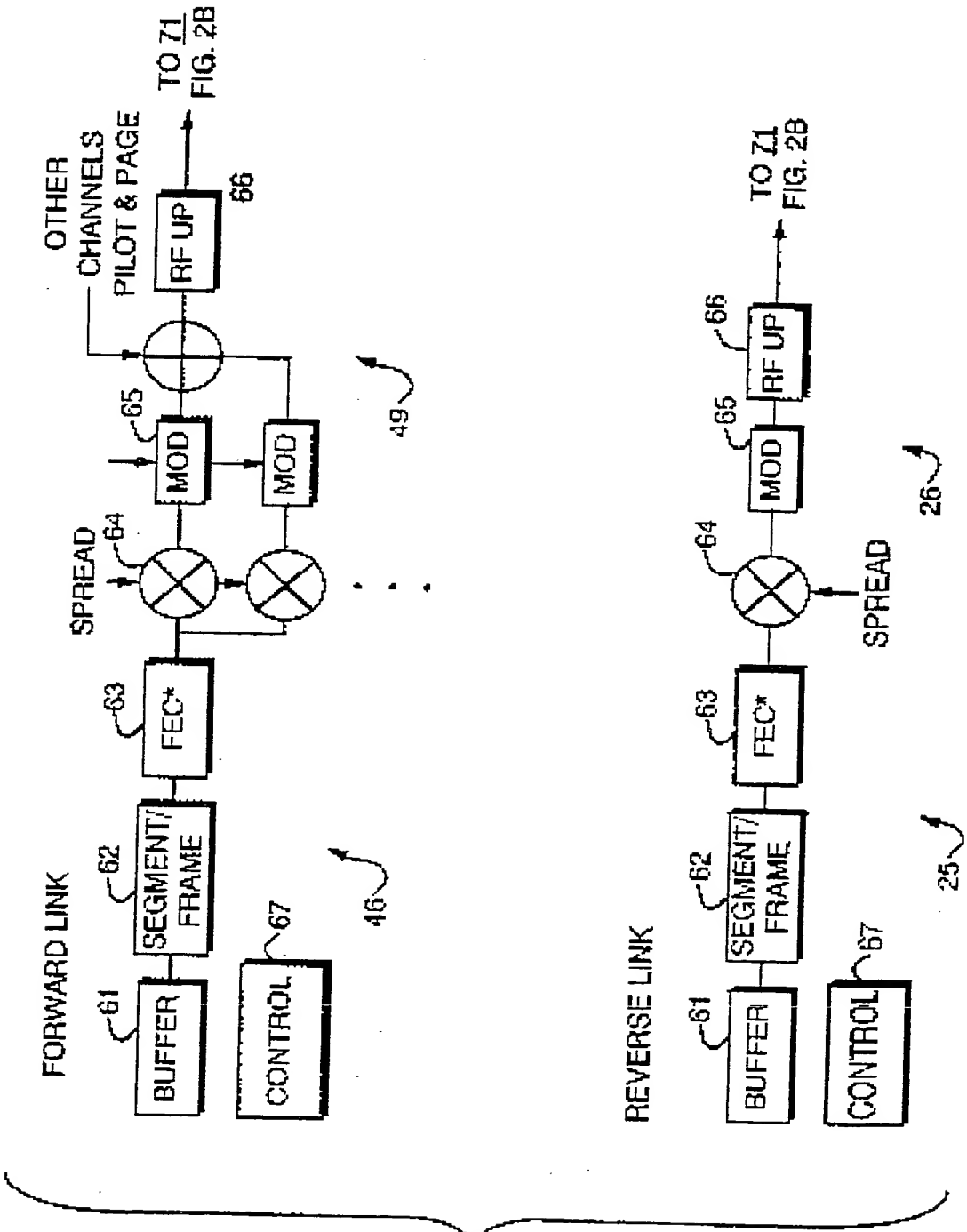

FORWARD LINK
BUFFER
61
SEGMENT/ FRAME
62
FEC*
63
SPREAD
64
MOD
65
RF UP
66
CONTROL
67
46
49
OTHER CHANNELS PILOT & PAGE
TO Z1 FIG. 2B
REVERSE LINK
25
26

FIG. 2A

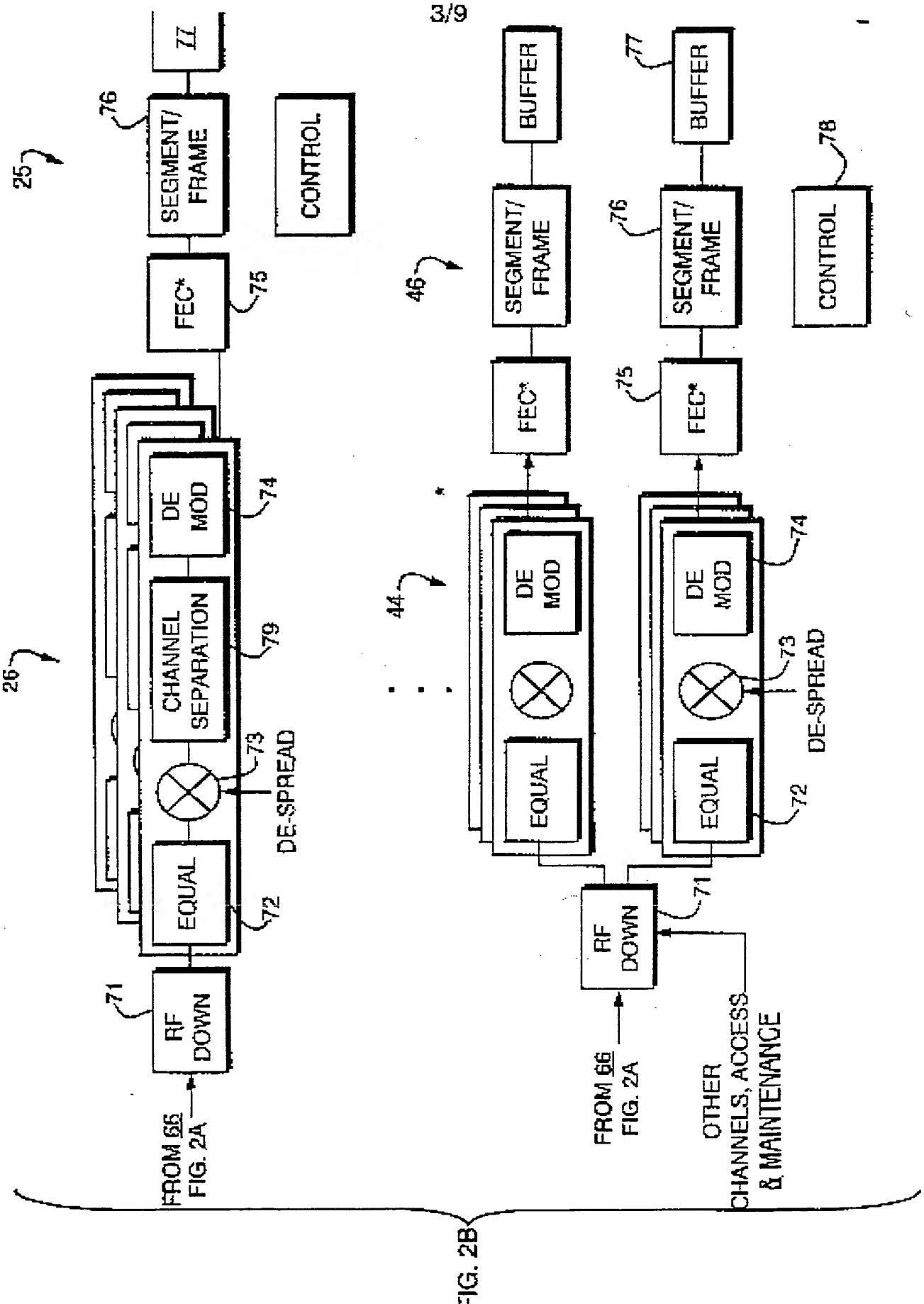

25
26
44
46
76
77
78
75
74
73
72
71
79
SEGMENT/ FRAME
CONTROL
FEC*
DE MOD
CHANNEL SEPARATION
EQUAL
RF DOWN
BUFFER
DE-SPREAD
FROM 66 FIG. 2A
OTHER CHANNELS, ACCESS & MAINTENANCE

FIG. 2B

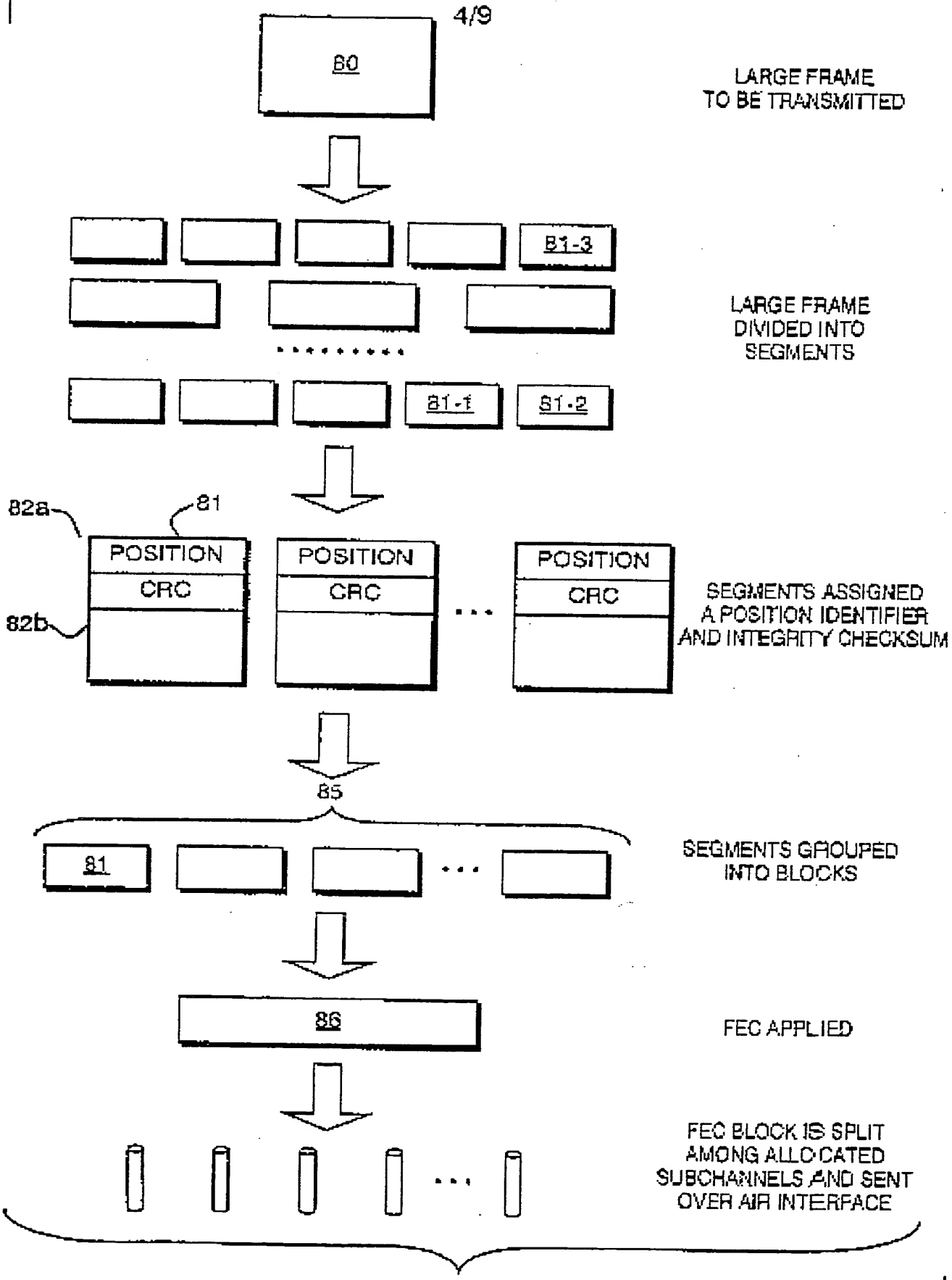


FIG. 3

SDOCID: <WO___0052831A2T1_>

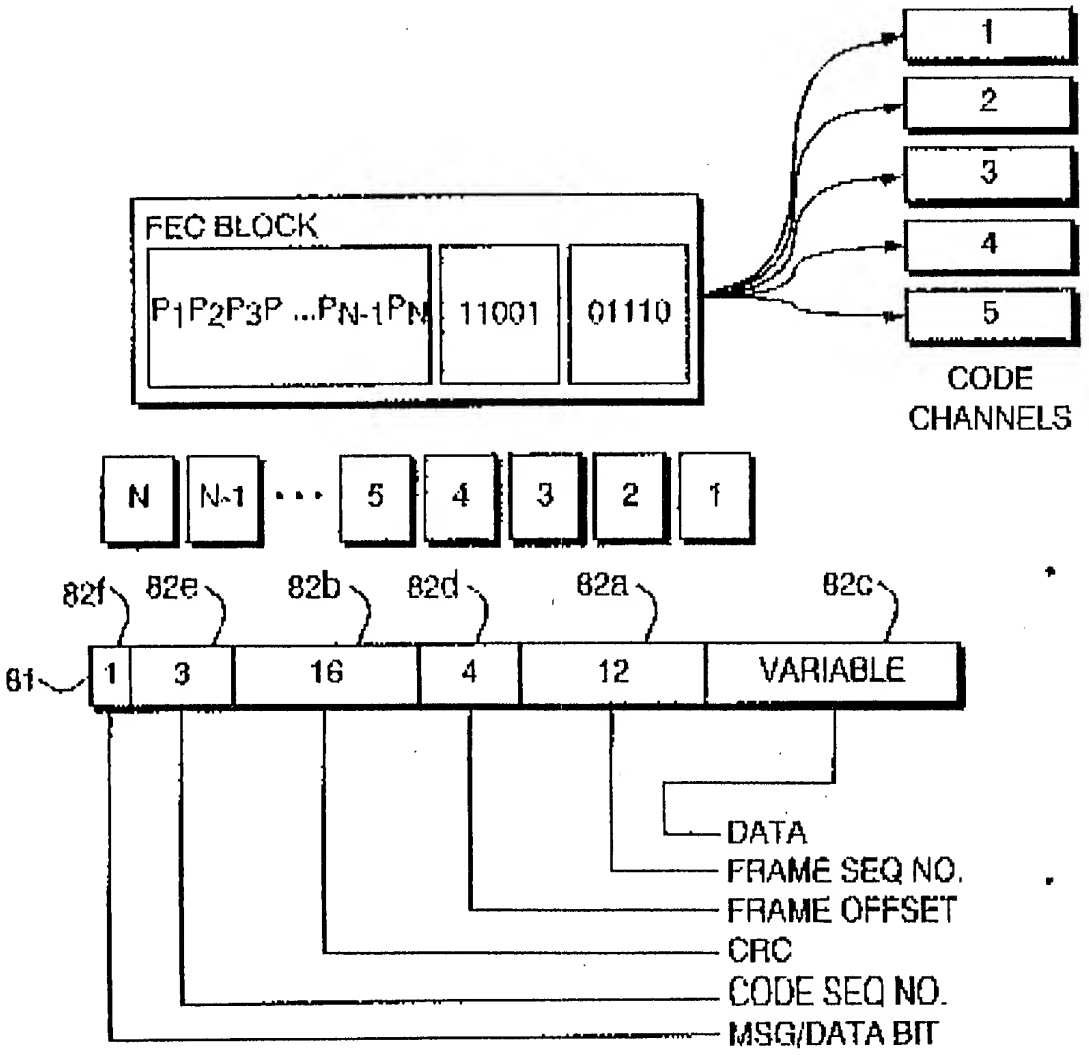


FIG. 4

- EACH FRAME IS SLICED INTO SEGMENTS AND SEGMENTS CAN BE VARIABLE IN LENGTH ACCORDING TO THE FER. THE MINIMUM SIZE IS 2 BYTES AND THE MAXIMUM IS 512 BYTES. ALL SEGMENTS ACROSS A FRAME ARE EQUAL IN SIZE.

- THE FEC BLOCK IS 4096 BITS (1331 INFORMATION BITS FOR RATE 1/3 TPC) AND IS INDEPENDENT OF THE FRAME SIZE.

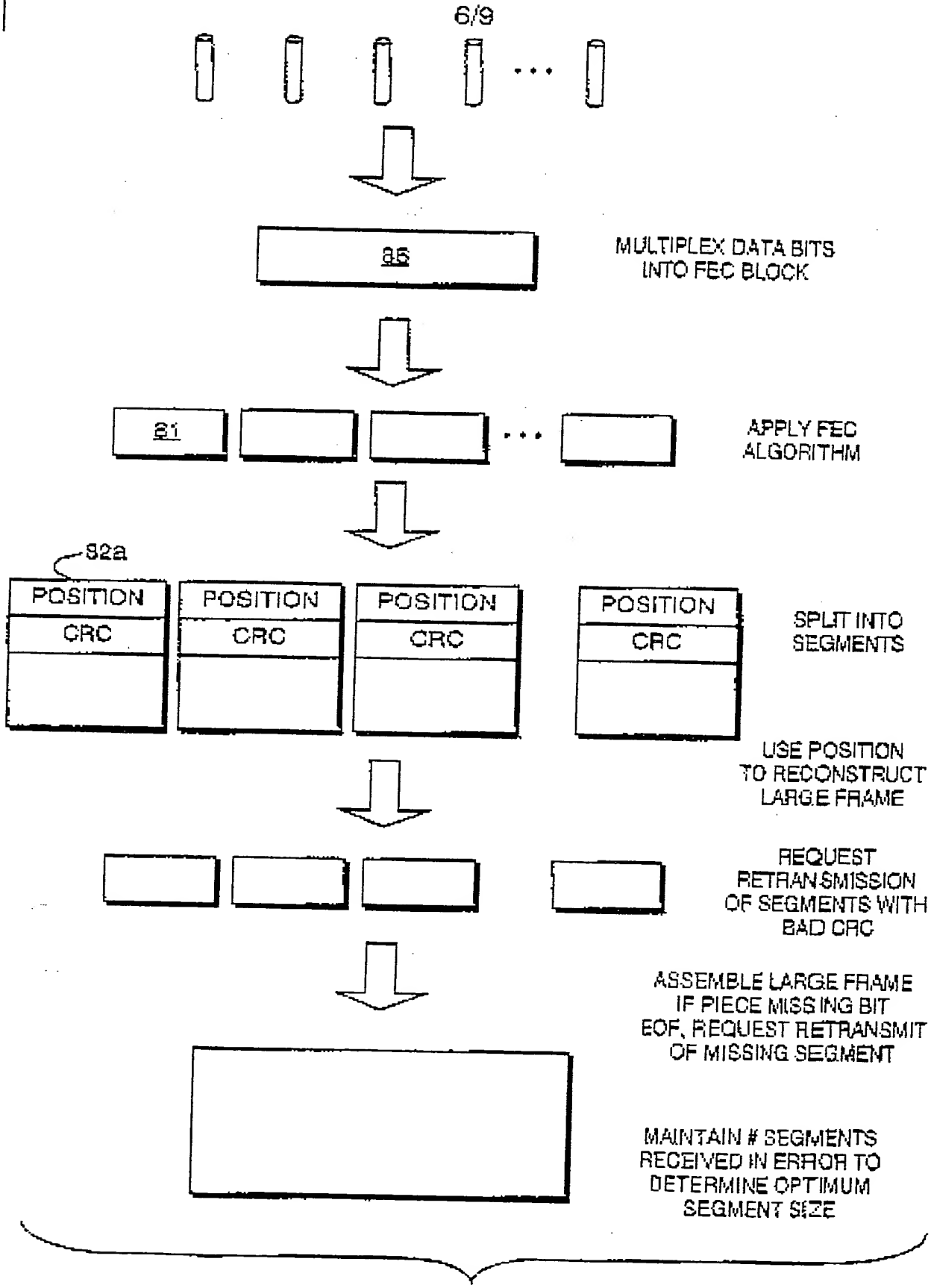

85
MULTIPLEX DATA BITS INTO FEC BLOCK
81
APPLY FEC ALGORITHM
82a
POSITION
CRC
POSITION
CRC
POSITION
CRC
POSITION
CRC
SPLIT INTO SEGMENTS
USE POSITION TO RECONSTRUCT LARGE FRAME
REQUEST RETRANSMISSION OF SEGMENTS WITH BAD CRC
ASSEMBLE LARGE FRAME IF PIECE MISSING BIT EOF, REQUEST RETRANSMIT OF MISSING SEGMENT
MAINTAIN # SEGMENTS RECEIVED IN ERROR TO DETERMINE OPTIMUM SEGMENT SIZE

FIG. 5

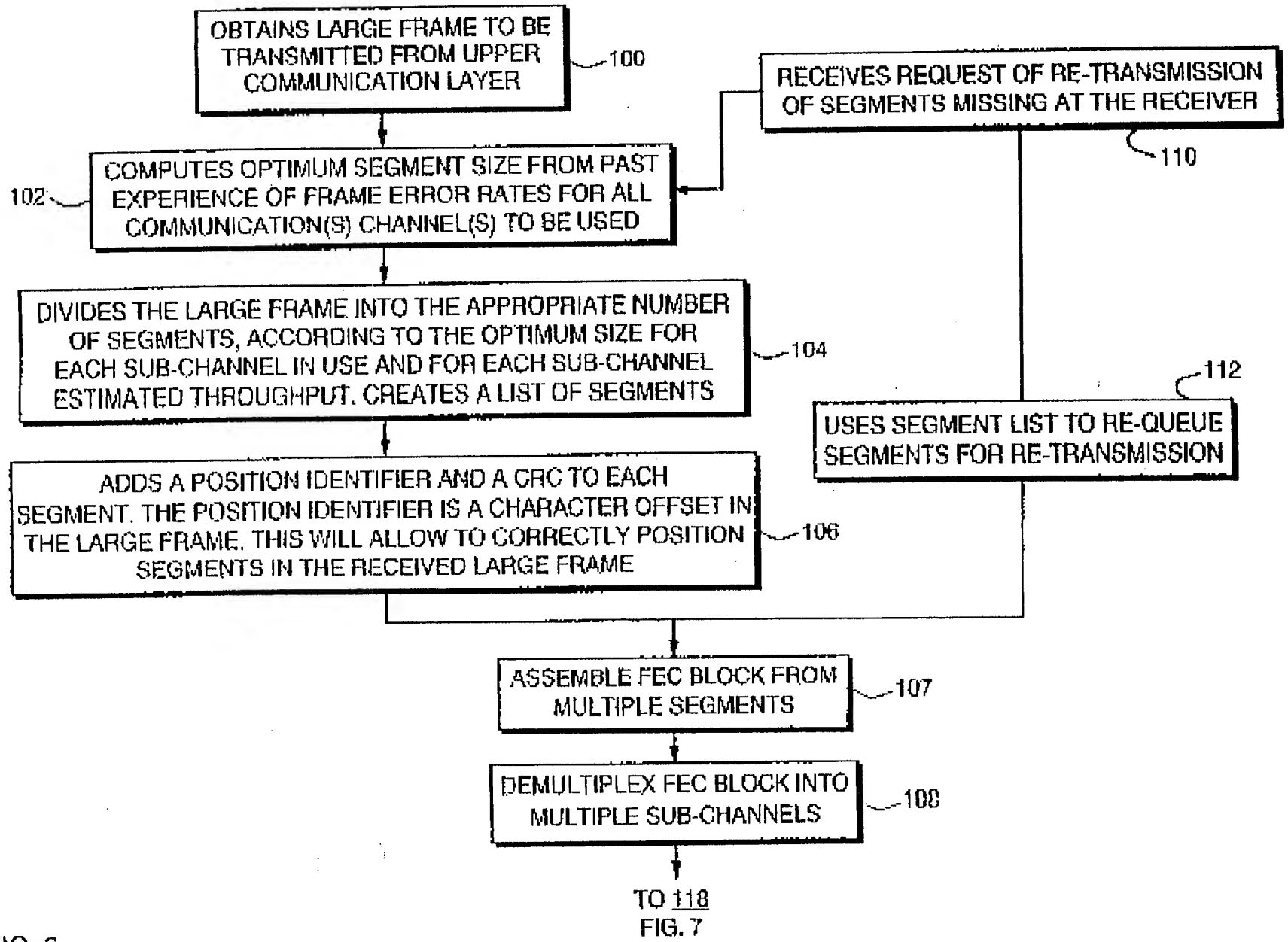


FIG. 7

FIG. 6

SUBSTITUTE SHEET (RULE 26)

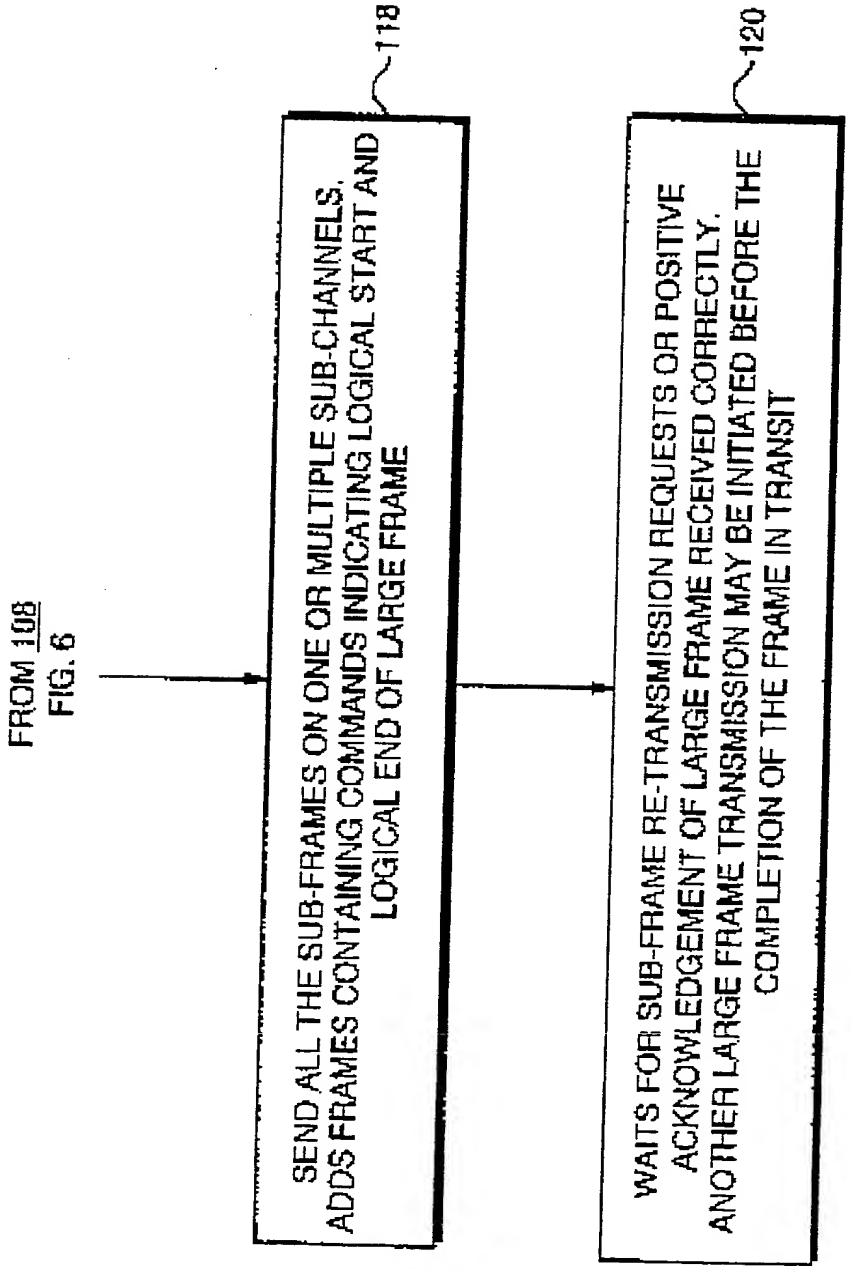

FROM 108
FIG. 6
SEND ALL THE SUB-FRAMES ON ONE OR MULTIPLE SUB-CHANNELS. ADDS FRAMES CONTAINING COMMANDS INDICATING LOGICAL START AND LOGICAL END OF LARGE FRAME
118
WAITS FOR SUB-FRAME RE-TRANSMISSION REQUESTS OR POSITIVE ACKNOWLEDGEMENT OF LARGE FRAME RECEIVED CORRECTLY. ANOTHER LARGE FRAME TRANSMISSION MAY BE INITIATED BEFORE THE COMPLETION OF THE FRAME IN TRANSIT
120

FIG. 7

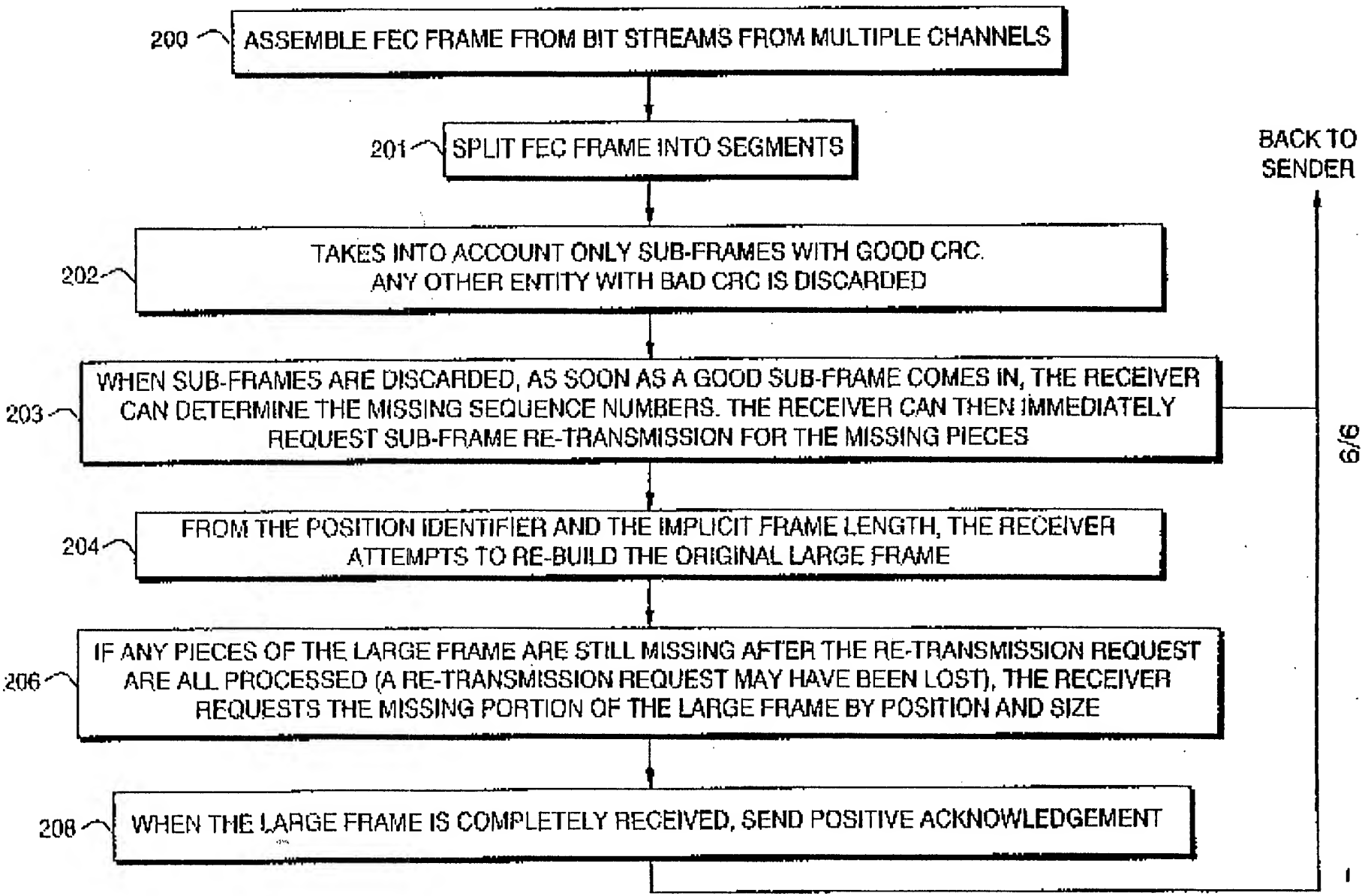

200
ASSEMBLE FEC FRAME FROM BIT STREAMS FROM MULTIPLE CHANNELS
201
SPLIT FEC FRAME INTO SEGMENTS
202
TAKES INTO ACCOUNT ONLY SUB-FRAMES WITH GOOD CRC.
ANY OTHER ENTITY WITH BAD CRC IS DISCARDED
203
WHEN SUB-FRAMES ARE DISCARDED, AS SOON AS A GOOD SUB-FRAME COMES IN, THE RECEIVER CAN DETERMINE THE MISSING SEQUENCE NUMBERS. THE RECEIVER CAN THEN IMMEDIATELY REQUEST SUB-FRAME RE-TRANSMISSION FOR THE MISSING PIECES
204
FROM THE POSITION IDENTIFIER AND THE IMPLICIT FRAME LENGTH, THE RECEIVER ATTEMPTS TO RE-BUILD THE ORIGINAL LARGE FRAME
206
IF ANY PIECES OF THE LARGE FRAME ARE STILL MISSING AFTER THE RE-TRANSMISSION REQUEST ARE ALL PROCESSED (A RE-TRANSMISSION REQUEST MAY HAVE BEEN LOST), THE RECEIVER REQUESTS THE MISSING PORTION OF THE LARGE FRAME BY POSITION AND SIZE
208
WHEN THE LARGE FRAME IS COMPLETELY RECEIVED, SEND POSITIVE ACKNOWLEDGEMENT
BACK TO SENDER

FIG. 8

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 September 2000 (08.09.2000)

PCT

(10) International Publication Number
WO 00/52831 A3

(51) International Patent Classification[7]: G11B 20/18, H03M 13/35, H04L 1/00

(21) International Application Number: PCT/US00/04580

(22) International Filing Date: 23 February 2000 (23.02.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/263,358 5 March 1999 (05.03.1999) US

(71) Applicant: TANTIVY COMMUNICATIONS, INC. [US/US]; Suite 300, 2200 Front Street, Melbourne, FL 32901 (US).

(72) Inventors: FERGUSON, Dennis, D.; 315 Triton Court, Indian Harbour Beach, FL 32937 (US). PROCTOR, James, A., Jr.; 440 Mosswood Boulevard, Indialantic, FL 32903-4007 (US).

(74) Agents: THIBODEAU, David, J., Jr. et al.; Hamilton, Brook, Smith & Reynolds, P.C., Two Militia Drive, Lexington, MA 02421 (US).

(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

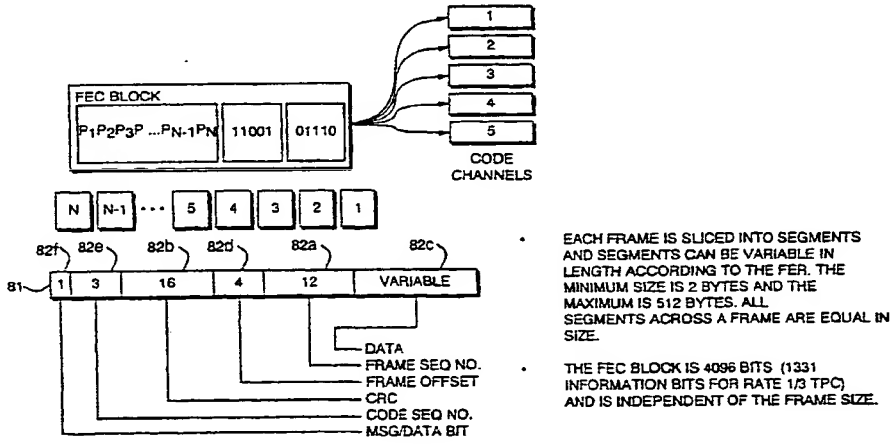
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

(88) Date of publication of the international search report:
21 December 2000

[Continued on next page]

(54) Title: FORWARD ERROR CORRECTION ON MULTIPLEXED CDMA CHANNELS ENABLING HIGH PERFORMANCE CODING



(57) Abstract: A protocol for optimizing the use of coded transmissions such as over wireless links. In this technique, interframes are first split into segments selected to be an optimum size according to transmission characteristics of the radio channel. Segments are assigned a position identifier and redundancy check sum. Segments are then assembled into blocks and a forward error correction algorithm is applied to the block to generate redundancy bits. The FEC block is then split up among available communication channels and forwarded to the receiver. The inverse process is applied at the receiver. Using this scheme, only segments containing erroneous data need to be resent. A large block size required for high performance forward error correction may therefore be used while at the same time minimizing latencies associated with the need to resend entire blocks when errors cannot be recovered.

WO 00/52831 A3

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/04580

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G11B20/18 H03M13/35 H04L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H03M G11B H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 98 59447 A (TANTIVY COMMUNICATIONS INC) 30 December 1998 (1998-12-30) cited in the application the whole document	1,5-8,10
Y	US 5 487 072 A (KANT KRISHNA) 23 January 1996 (1996-01-23) column 5, line 1 -column 9, line 18; figures 1-3	1,5-8,10
A	WO 96 13914 A (POWER SPECTRUM TECH LTD ;SILBERSHATZ GIORA (IL); LUPU VALENTIN (IL) 9 May 1996 (1996-05-09) page 153, line 16 -page 157, line 26; claims 15,16; figures 78-81	1-3,5-7, 10

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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Date of the actual completion of the international search	Date of mailing of the international search report
17 August 2000	25/08/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Devergranne, C

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